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FISCAL YEAR 1987 DEPARTMENT OF ENERGY AUTHORIZATION

(Transportation Programs)

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HEARINGS

BEFORE THE

SUBCOMMITTEE ON TRANSPORTATION, AVIATION AND MATERIALS

OF THE

COMMITTEE ON
SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

NINETY-NINTH CONGRESS

SECOND SESSION

FEBRUARY 25 AND 27, 1986

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**Serving on Committee on the Budget for 99th Congress.

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FISCAL YEAR 1987 DEPARTMENT OF ENERGY AUTHORIZATION

(Transportation Programs)

TUESDAY, FEBRUARY 25, 1986

House of Representatives,
Committee on Science and Technology,
Subcommittee on Transportation,
Aviation, and Materials,
Washington, DC.

The subcommittee met, pursuant to notice, at 9 a.m., in room 2325, Rayburn House Office Building, Hon. George E. Brown, Jr. (chairman of the subcommittee) presiding.

Mr. **Brown**. The subcommittee will come to order.

Today, the Subcommittee on Transportation, Aviation, and Materials will begin 2 days of hearings on the Department of Energy's fiscal year 1987 budget request for transportation. These programs were largely mandated by two bills which originated in the Science and Technology Committee; the Automotive Transport Research and Development Act and the Electric Vehicle Research, Development, and Demonstration Act, so we are particularly interested in reviewing their progress.

Transportation uses more petroleum-derived fuel—over 60 percent—than all other energy consuming sectors in the United States combined, and accounts for nearly 30 percent of all energy consumed in this country. Thus, the Department of Energy's vehicle and engine research and development programs are focused directly at improving the energy efficiency of the sector which shows the most potential for providing substantial reductions in our dependence on foreign oil. Clearly, we must recognize the importance of these research and development programs as a key component of our long-term national security.

The budget request for fiscal year 1987 is $19.8 million, less than half of what was appropriated for fiscal year 1986. While many of the automotive programs are moving successfully toward achieving the goals set out in the enacting legislation, we still have a long way to go in establishing the key ceramic and advanced materials technology base upon which these engines rely. Likewise, advancements in battery and electric vehicle technology, while encouraging, still have not reached their full potential. While we all are aware of the current budget situation, it is the responsibility of Congress to review the priorities proposed by the budget request to determine if they are indeed in the best interests of the Nation.

I look forward to a very informative and productive hearing, and welcome the expert witnesses who have agreed to assist the subcommittee today.

Mr. Lewis has a statement also; do I understand? And we'll put it in the record at this point. Either of you gentlemen have any statements?

[The prepared opening statement of Mr. Lewis follows:]

OPENINING STATEMENT OF HON. TOM LEWIS

Thank you, Mr. Chairman, the 1987 budget process is just beginning, but already it looks as if we are in for a difficult year.

We've tried for too long to satisfy to many interests. This year, thanks to Gramm-Rudman, the day of reckoning has arrived.

The budget that we will be reviewing here this morning will be particularly difficult. The Administration has proposed terminating or significantly scaling back a number of DOE's transportation programs, and all of these programs have their advocates.

Our job would be made much easier if these were useless programs or if there were evidence of mismanagement. However, this is not the case.

Waste, fraud, and abuse are easier to talk about than to identify, and in spite of the current petroleum glut, the goals of DOE's energy conservation programs are still valid today.

This year it will be especially important for the Administration and Congress to work together to ensure, not only that the maximum benefits possible are realized from the limited resources available, but also that, in terminating programs in the interes of economy, the benefits of dollars already spent are not lost.

industry has responsibility in this regard also. I think it's appropriate to ask them to assume a larger role in bringing these technologies to the market place.

Mr. Chairman, I join you in welcoming our witnesses this morning and I look forward to hearing their testimony.

Thank you.

Mr. **LUJAN**. None.

Mr. **BROWN**. All right.

We welcome you, Miss Fitzpatrick, and you may proceed with your statement.

STATEMENT OF DONNA FITZPATRICK, ASSISTANT SECRETARY FOR CONSERVATION AND RENEWABLE ENERGY, ACCOMPANIED BY AL STREB, DEPUTY ASSISTANT SECRETARY FOR CONSERVATION, AND DR. MEL CHIOGIOJI, DIRECTOR, OFFICE OF TRANSPORTATION SYSTEMS

Miss **FITZPATRICK**. Thank you, Mr. Chairman. I have a detailed statement I would like to submit for the record.

Mr. **BROWN**. Without objection, it will be included in full.

Miss **FITZPATRICK**. Thank you. And I will summarize it orally, if I may.

I'd like to introduce my colleagues here at the table. I'm accompanied on my right by Mr. Al Streb, who is the Deputy Assistant Secretary for Conservation, and on my left, Dr. Mel Chiogioji, who is the Director of the Office of Transportation Systems.

Mr. **BROWN**. We welcome both of these gentlemen also.

Miss **FITZPATRICK**. We appreciate the opportunity to appear before the subcommittee today and provide information on our fiscal year 1987 budget request concerning the Department's energy conservation research and development programs in transportation. The budget for this program supports the goals and strategies of our national energy policy as well as the administration and congressional goal of deficit reduction.

The administration's goal in energy policy continues to be that of fostering an adequate supply of energy at a reasonable cost. The strategies for obtaining this goal encompass the maximum practical reliance on free market place decisions.

The objectives of the Department's energy conservation research and development programs in transportation are: to contribute to improved energy efficiency and to enhance the diversity of available end-use technologies in transportation. These programs provide the technology base which is necessary to support private sector efforts to develop technologies which are either more efficient or serve as alternatives to those which are based exclusively on petroleum.

In allocating our resources, we are concentrating on applying Federal funds where they can be most effective by sponsoring longer term, higher risk research and development for which the potential payoff is high but which [illegible]ate industry is unlikely to pursue alone.

The fiscal year 1987 budget request [illegible] vehicle propulsion R&D provides $4 million to initiate a foll[illegible] turbine component development project which will utilize the component development experience and the ceramic industry subcontractor relationships which have been established by the present automotive gas turbine contractor teams and the existing test rigs and experimental engines.

The objectives of the follow-on project are: To continue the development of ceramic components for gas turbine applications in parallel with the Advanced Materials Development Program; and to establish the reliability of component designs and materials, expand the experimental data base in the operating environment, and develop the analytical tools required for ceramic component design.

In the automotive Stirling engine project, preliminary testing of a prototype Mod II engine on a dynamometer is scheduled to be completed in April. At that time, all of the engine designs and the test data for both the Mod I and the Mod II engines, the results of industry evaluations, and the prototype engines themselves will be available for transfer to industry.

Since this transfer of the developed technology will essentially accomplish the Federal program goals under our proof of concept strategy, we are not requesting funds for Stirling engine R&D in fiscal year 1987.

A total of $2.5 million has been requested for continuation of the heavy duty adiabatic diesel project. Component evaluations of developed ceramic structures in a single-cylinder test cell will be continued, and the actual design, by industry, of a baseline multicylinder adiabatic diesel system will be carried out. Initial experimental emissions evaluations for uncooled diesel operations will be conducted, and the heat transfer models for adiabatic diesel operation will be continued.

We have requested $1.3 million for the Alternative Fuels Utilization Program to continue the data collection and analysis of the methanol-fueled vehicle fleet operations and to continue performance investigations on conventional and advanced single and multicylinder engines using synthetic fuels. Test synthetic fuels will continue to be made for project activities and the scientific community. $4.1 million has been requested for Electric and Hybrid Vehicle R&D where the primary focus continues to be on the development of battery technology for vehicle propulsion.

In fiscal year 1987, the development of full-size experimental cells and modules of the flow-through lead-acid technology will be completed and delivered for laboratory testing and evaluation. The development of the electric vehicle's sodium-sulfur technology will be continued, with emphasis on the unique performance requirements for an electric van application, including cell development, cell interconnect strategy, and thermal management.

A zinc-bromine eight-cell battery stack will be delivered for laboratory testing utilizing the most advanced materials and electrolyte formulations.

Efforts will continue in fiscal year 1987 on the dual-shaft alternating current propulsion system technology for commercial van application, with emphasis on the integration of the vehicle control systems and the nickel-iron battery, including the single-point watering and the thermal management systems.

The design phase only of the second generation ETX-II single-shaft alternating current propulsion system will be completed in fiscal year 1987, and the hardware fabrication of components will be terminated. We are, therefore, not requesting additional funds for the ETX-II project in fiscal year 1987.

Fleet operational testing of new electric vehicle technologies will be phased out after completion of the testing and evaluation of current product improvements. Funding is requested to complete the laboratory and in-vehicle dynamometer testing at the Idaho National Engineering Laboratory.

The fiscal year 1987 request provides $6.5 million for the Advanced Materials Development Program. Program activities will include projects on materials and processing of monolithic silicon nitride and silicon carbide, oxide matrix and dispersion toughened composites, thermal and wear zirconia-based coatings, dynamic interfaces, data base/life prediction, and International Energy Agency standardization of ceramic materials and testing. The excellent coordination procedures established with both Government and industry laboratories will be maintained, and the National Materials Advisory Board Committee, established to review program planning and implementation, will be continued.

During fiscal year 1987, the High Temperature Materials Laboratory will initiate operations and begin placement of permanent User Staff personnel. Based on the fundamental and cross-cutting nature of the operations to be conducted at the laboratory, funding for the operational research staff will be provided from the Office of Basic Energy Sciences in the Department's Office of Energy Research. Therefore, no additional funds have been requested for this project within our budget.

Finally, we are requesting $1.4 million for 22 full-time equivalent positions to provide direction and management to the transportation programs.

In summary, the activities of the Department's transportation program cover a spectrum of projects structured to increase energy efficiency and reduce petroleum dependence in the transportation sector. Although the program is focused on the transportation sector, the technologies under development for high-temperature materials, advanced propulsion systems, batteries, and alternative fuels utilization have a wide range of applications in addition to transportation.

That concludes my statement, Mr. Chairman. I thank you for the opportunity to appear here today.

[The prepared statement of Miss Fitzpatrick follows:]

STATEMENT OF

DONNA R. FITZPATRICK

ASSISTANT SECRETARY

CONSERVATION AND RENEWABLE ENERGY

BEFORE THE

COMMITTEE ON SCIENCE AND TECHNOLOGY

TRANSPORTATION, AVIATION AND MATERIALS SUBCOMMITTEE

U.S. HOUSE OF REPRESENTATIVES

FEBRUARY 25, 1986

Mr. Chairman and Members of the Subcommittee, I appreciate the opportunity to appear before you today and provide information on the FY 1987 budget request concerning the Department's energy conservation research and development programs in the transportation area. The budget fully supports the goals and strategies of the Fifth National Energy Policy Plan. I will summarize those parts of the Plan which are relevant to the subject of today's hearing and discuss highlights of the FY 1987 budget.

NATIONAL ENERGY POLICIES AND STRATEGIES

Our national energy policy goal and strategies are intended to lead us along a pathway to growing energy stability, security, and strength. The Administration's goal in energy policy continues to be that Americans should have an adequate supply of energy, maintained at a reasonable cost. The strategies for attaining this goal encompass the maximum practical reliance on the free decisions of the people.

The strategies for achieving this energy policy goal are:

- to minimize Federal control and involvement in energy markets while maintaining public health and safety and environmental quality; and
- to promote a balanced and mixed energy resource system.

The FY 1987 budget implements these strategies by supporting development of a mix of technologies that can contribute to both energy supply and improved end-use efficiency. In allocating our resources, we are concentrating on applying Federal funds only where they are most effective by sponsoring longer-term, high-risk research and development for which the potential payoff is high but which private industry is hesitant to pursue. CE programs will be exploring cooperative research and development approaches with industry that would seek DOE partnership and support in technologies associated with vehicle propulsion. Participation in industry-formed cooperative R&D ventures to support longer-term, applied technology development may be an effective method to leverage scarce Federal resources. The budget continues the Administration's policy of not funding commercialization activities which are the proper province of the private sector.

TRANSPORTATION RELATED GOALS AND OBJECTIVES

The objectives of the Department's energy conservation research and development programs in the transportation area are to contribute to improved energy efficiency and enhanced diversity of available end-use technologies. These programs provide the technology base necessary to support private sector efforts to develop technologies which are either more efficient or serve as alternatives to those based exclusively on petroleum.

The importance of our efforts in this area is underscored by the fact that the transportation sector accounted for 27 percent of total U.S. energy consumption in 1985 and, more importantly, 63 percent of U.S. petroleum consumption, up from 51 percent in 1973. During this period, the private sector has made substantial investments in more efficient transportation technology and major improvements have been made, as evidenced by the fact that the average fuel economy of 1985 model year automobiles was 90 percent better than that for 1973 model year automobiles. Nevertheless, further technological improvements are possible in energy efficiency and in fuel flexibility. Our program focuses on highway vehicles because three-fourths of petroleum use in transportation is by highway vehicles. The remaining one-fourth is attributable to other modes, including rail, air, and marine.

FY 1987 BUDGET

The FY 1987 budget in the transportation area requests $19.8 million for operating expenses. This funding is required to continue a program of research and development based on specific strategies generated in accordance with industry inputs. The strategies include efforts to: (a) establish proofs-of-concepts and develop advanced heat engine technologies which have at least a 30 percent improvement in fuel efficiency over comparable conventional engines, meet emission, safety, and noise standards, have alternative fuels capability, and have competitive life-cycle costs; (b) advance battery and propulsion system technology for competitive electric and hybrid vehicles for passenger car, van, or light truck applications; (c) establish a fundamental ceramic and advanced materials technology base for heat engines; and (d) develop a utilization-oriented technology base for use of nonpetroleum-based fuels made from oil shale, coal, and biomass in both contemporary and advanced propulsion systems.

I would now like to describe our progress, our planned activities during FY 1986, and our request for FY 1987 for each of the sub-programs in the areas under your jurisdiction.

VEHICLE PROPULSION R&D

To achieve the objectives specified in P.L. 95-238, the Automotive Propulsion Research and Development Act of 1978, research and development has been pursued to establish technology bases for three advanced engine concepts: the automotive gas turbine (AGT), the automotive Stirling engine, and the heavy duty adiabatic (uncooled, minimum friction) diesel engine. Common to all of these advanced engine concepts is the requirement to develop improved high-temperature materials and components.

The Automotive Gas Turbine (AGT) project has been implemented through cost-shared proof-of-concept engine development contracts with two industry teams. A single-shaft configuration (AGT 101) is being developed by Garrett Corporation/Ford Motor Company and a two-shaft concept (AGT 100) by Allison Gas Turbine Division/Pontiac Motor Division of General Motors.

Application of high-temperature structural ceramic components is a critical technology barrier in both concepts because of the high operating temperatures necessary to achieve efficiency goals. Both industry teams have successfully integrated prototype ceramic components into engine builds at increasing temperature and power levels. By the end of FY 1986, both teams are scheduled to demonstrate proof-of-concept of a fully ceramized gas turbine engine on a dynamometer with the capability for operations at the temperature ranges and rotating speeds required. Although such a demonstration will represent a major breakthrough in gas turbine technology and, even more significant, an industry-wide capability to fabricate ceramic components from a variety of materials in complex near-net-shapes, more development is needed before the design and fabrication of ceramic components reaches the reliability and long-life requirements of advanced propulsion systems. This situation was recognized several years ago when the Advanced

Materials Development (AMD) Program was initiated to conduct the basic ceramics research necessary to establish a sufficient technology base from which industry could produce reliable, cost-effective engine components. In order for this strategy to be completely successful, an iterative mechanism must be available where the research results from the AMD program are fabricated into real engine components, tested under actual operating engine environments, and evaluation results fed back into the AMD research agenda. To assure that this important mechanism continues after the completion of the automotive gas turbine program, we have requested $4 million in FY 1987 to initiate a follow-on program which will utilize the component development experience and ceramic industry subcontractor relationships established by the present AGT contractor teams, and the existing test rigs and experimental engines. The objectives of the follow-on program are to continue the development of ceramic components for gas turbine applications in parallel with the AMD program, and to establish the reliability of component designs and materials, expand the experimental data base in the operating environment, and develop the analytical tools required for ceramic component design.

The Automotive Stirling Engine (ASE) project has focused on the development of a proof-of-concept engine with an industry team lead by Mechanical Technology, Incorporated (MTI), combined with United Stirling AB & Company of Sweden. Under this program, transfer of Stirling engine technology to the United States has now been accomplished. Over 14,000 hours of performance testing has been completed on seven MOD I experimental engines fabricated under the program and predicted performance goals for the design have been confirmed. Testing of an Upgraded MOD I

(MOD IA) engine, which operates at a higher heater-head temperature and contains much less strategic metal has also been completed. The evaluations of the two MOD I engines loaned to industry in FY 1984 have now been completed and the final design of a second generation engine configuration, the MOD II engine, was completed in FY 1985.

During FY 1985 and continuing in FY 1986, additional efforts to transfer the Stirling technology developed to other Government agencies and industry are being carried out. A MOD I engine has been loaned to the U.S. Army for installation in a military generator set. Negotiations are in progress to loan a MOD I engine to the Air Force for a van installation. Announcements have also been made in the Commerce Business Daily on the availability of MOD I Stirling engines for loan to industry for non-automotive application evaluations. NASA has maintained a close coordination with the program for possible application of Stirling technology for power in the space station project.

Testing of a prototype MOD II engine on a dynamometer will be completed during the first six months of FY 1986. At that time, all of the engine designs and test data for both the MOD I and MOD II engines, the results of industry evaluations, and the prototype engines themselves will be available for transfer to industry. Based on this information and equipment, industry can perform the assessments necessary to determine whether further commercialization efforts should be carried out. Since this transfer of developed technology will essentially accomplish the Federal program goals under our "proof-of-concept" strategy, we are not requesting funds for Stirling engine R&D in FY 1987. Phase-out program costs will be covered under FY 1986 appropriated funds and any surplus funding will be deferred.

The Heavy Duty Transport Technology project has focused on establishing a technology data base for industry development of uncooled, minimum friction, low heat rejection diesel engines (commonly referred to as adiabatic diesel engines). Elimination of the cooling system, with attendant high operating temperatures and recovery of the increased exhaust heat energy, offers the potential for greatly improved operational fuel economy (30 to 40 percent better) compared with 1982 technology. The research strategy has been to concentrate on technology barriers identified by industry and to plan development activities in such a way as to support industry efforts to introduce individual components and concepts. During FY 1986, evaluations of developed ceramic components will be initiated in a single-cylinder test cell, and industry requirements for the design of a baseline multi-cylinder adiabatic diesel system finalized. Development of a heat transfer model for high temperature diesel engine operations will be continued and second stage component development requirements identified. In FY 1987, developed component evaluations will be continued in single-cylinder test cells and the actual design by industry of a baseline system will be carried out. Initial experimental emissions evaluations for uncooled diesel operations will be conducted, and the heat transfer models for adiabatic diesel operation will be completed. A total of $2.5 million has been requested in FY 1987 for continuation of the Heavy Duty Transport Technology Development project.

Technology Assessment and Transfer activities of the Vehicle Propulsion R&D subprogram will be continued in FY 1987 to provide an ongoing assessment of related private sector developments and other Government-sponsored programs to assure that maximum coordination with industry is maintained, both for dissemination of research results and gathering of inputs on technology needs. These activities will be integrated with related subprogram activities and no separate funding has been requested for FY 1987.

ALTERNATIVE FUELS UTILIZATION

The goal of the Alternative Fuels Utilization Program is to establish a utilization oriented data base for alternative fuels in both contemporary and advanced heat engines. The approach has been to conduct systematic research on the fundamentals of alternative fuel use in both spark ignition and diesel engines, concentrating on nearer-term fuels first (alcohols) and expanding the data base in subsequent stages to include synthetic fuels and advanced engines.

During FY 1986, basic fuel/engine performance/emissions investigations are being continued to identify and provide understanding of engine problems associated with the use of synthetic fuels, and the facility at Southwest Research Institute will continue to provide industry and the scientific community with standardized synthetic test fuels. The Federal fleet methanol-fueled vehicle demonstration will begin operations with at least four different production vehicle types in three fleet locations. In FY 1987, the data collection and analysis of the methanol-fueled vehicle fleet operations will be continued and performance investigations on conventional and advanced single- and multi-cylinder engines using synthetic fuels will also be continued. Test synthetic fuels will continue to be made for project activities and the scientific community. A total of $1.3 million has been requested in FY 1987 for this program.

ELECTRIC AND HYBRID VEHICLE R&D

The goal of P.L. 94-413, the Electric and Hybrid Vehicle Research, Development and Demonstration Act of 1976, is to develop the technology, in cooperation with industry, that will lead to the production and introduction of electric vehicles into the Nation's transportation fleet and the substitution of more abundant sources of energy for petroleum-based fuels. Significant progress is being made in the Department's program and by the private sector in developing the technology of batteries and propulsion systems in order to achieve that goal. After intensive characterization testing by the Idaho National Engineering Laboratory, six General Motors Griffon electric vans have been placed into operational fleet testing by Detroit Edison in the Department's cost-shared test and evaluation program. More than thirty of these electric vans are being placed in fleets throughout the country by the private sector in a program coordinated by the Electric Vehicle Development Corporation.

The primary focus of the electric and hybrid vehicle program continues to be on the development of battery technology for vehicle propulsion. In FY 1986, the development of an advanced lead-acid battery based on the forced flow of electrolyte through porous lead and lead dioxide electrodes is continuing. This technology offers a 51 percent improvement in active material utilization over current lead-acid battery technology, resulting in a major increase in the specific energy of lead-acid batteries. Laboratory tests of experimental cells have demonstrated the viability of the flow-through concept. In addition, the flow-through technology would significantly increase the cycle life of lead-acid batteries. In FY 1987, the development of full-size experimental cells and modules of the flow-through lead-acid technology will be completed and delivered for laboratory testing and evaluation. In FY 1986, a contract is being negotiated for the development of sodium-sulfur battery technology for the electric vehicle application, based on the core technology development funded by the Energy Storage and Distribution Division. For the electric propulsion application, the optimum cell configuration and interconnect strategy as well as the thermal management system are being investigated. In FY 1987, the development of the electric vehicle sodium-sulfur technology will be continued with emphasis on the unique performance requirements for an electric van application including cell development, cell interconnect strategy, and thermal management.

In FY 1986, the development of zinc-bromine battery technology for the electric vehicle application is being continued. Significant progress is being made on controlling electrode warpage to an acceptable minimum and increasing the reliability of the complete battery subsystem. Initial tests of experimental cells in compression are demonstrating improved performance and longer cycle life over current cell designs. In FY 1987, a zinc-bromine 8-cell battery stack will be delivered for laboratory testing utilizing the most advanced materials and electrolyte formulations.

In addition to battery technology development, the program is also developing an advanced electric vehicle propulsion system. In FY 1986, the second generation of the single-shaft a.c. propulsion system (ETX-II) was continued for an electric van application. The first generation powertrain was installed in a proof-of-concept passenger car and tested on a dynamometer and on a test track. A full-scale zinc-bromine experimental battery and a portion (1/3 scale) of an experimental sodium-sulfur battery have been successfully tested as part of the propulsion system. An experimental full-scale tubular-plate lead-acid battery has been delivered and is under test as part of the propulsion system evaluation. For the second generation system a full-scale permanent magnet (neodymium-iron) motor, together with breadboards of the associated power electronics and control systems, have been fabricated. In FY 1987, the design phase only of the second generation single-shaft a.c. propulsion system will be completed using unexpended prior year obligations and hardware fabrication of components will be terminated.

In FY 1986, research and development of a dual-shaft a. c. propulsion system is being continued for an electric van application. This effort includes the development and vehicle integration of nickel-iron battery technology. The powertrain incorporates a two-speed automatically shifted transaxle with regenerative braking. In FY 1987, the development of the propulsion system will be continued with emphasis on the integration of the vehicle control systems and the nickel-iron battery subsystem including the single-point watering system and the thermal management system.

In FY 1986, testing and evaluation activities of electric vehicle technology include operational fleet testing and laboratory and in-vehicle dynamometer testing. Characterization testing of the General Motors Griffon electric van and the Eaton a.c. propulsion system was completed with in-vehicle dynamometer testing at the Idaho National Engineering Laboratory. Phase III gel cell batteries developed in the program were installed in vehicles and are being fleet tested by GTE, the University of Hawaii, and Sandia National Laboratory. Preliminary field test results of the gel cell batteries are consistently showing a significant reduction in energy use per mile compared to the flooded lead-acid batteries that were replaced in the vehicles, elimination of the battery maintenance problem, and increased overall system reliability. Additional product improvements such as nickel-iron and tubular-plate lead-acid experimental batteries and watering systems have been installed in vehicles by the User Task Force and are being tested and evaluated in fleet operations. In FY 1987, the fleet operational testing will be phased out after completion of the testing and evaluation of the product improvements program. Funding is requested in FY 1987 to complete the laboratory and in-vehicle dynamometer testing at the Idaho National Engineering Laboratory.

The total funding request for the Electric and Hybrid Vehicle R&D program in FY 1987 is $4,140,000.

ADVANCED MATERIALS DEVELOPMENT

Improved materials technology is a key requirement in all transportation propulsion R&D activities. In high performance energy conversion systems, and in particular in advanced transportation engines, operation at high temperatures in corrosive environments is essential for obtaining substantially improved efficiencies. A critical need is the development of ceramic, ceramic composite, or ceramic coated components which can withstand these operational environments. Although the advanced engine projects are providing the required focus to prove the feasibility of ceramic components, they have also demonstrated that a parallel basic ceramics research effort is necessary to assure future development of reliable and reproducible ceramic parts. The goal of the Advanced Materials Development Program is to establish an industrial ceramic technology base capable of providing reliable and cost-effective components for high-temperature, efficient propulsion systems while eliminating requirements for scarce strategic materials.

In accordance with the basic ceramic technology areas identified in the program plan--developed through a comprehensive industry assessment--research activities in FY 1986 will include continuation of projects for improved silicon carbide and silicon nitride powders, ceramic composites, thermal and wear coatings, joining ceramic-to-metal and ceramic-to-ceramic, life prediction and characterization of ceramic properties. During FY 1987, the phased activities on existing contracts and research projects will be continued, and some new research projects will be initiated essentially in accordance with a high pay-off focus of the program plan technology areas. Program activities will include projects on materials and processing of monolithic silicon nitride and silicon carbide, oxide matrix and dispersion toughened composites, thermal and wear zirconia-based coatings, dynamic interfaces, data base/life prediction, and International Energy Agency standardization of ceramic materials and testing. The excellent coordination procedures established with both Government and industry laboratories will be maintained and the National Materials Advisory Board committee, established to review program planning and implementation, will be continued. We have requested $6.5 million for the Advanced Materials Development Program in FY 1987.

The High Temperature Materials Laboratory (HTML) at Oak Ridge National Laboratory was initiated in FY 1983 to support advanced high-temperature ceramic and alloy materials research in both Government and industry. The HTML will have a unique capability with a broad multidisciplinary professional staff serving as a common focal point for industrial/university/Government participation and having access to high-cost research equipment. During FY 1986, construction on the laboratory facility will be continued and procurement of major items of research equipment will be initiated. In early FY 1987, the construction will be completed and equipment installation implemented with unexpended prior year construction obligations. During FY 1987, the HTML will initiate operations and begin placement of permanent User Staff personnel. Based on the fundamental and cross-cutting nature of the operations to be conducted at the HTML, funding for the operational research staff will be included in the Basic Energy Sciences budget of the Office of Energy Research. Therefore no additional funds have been requested for this project.

PROGRAM DIRECTION

To provide the overall program direction of the transportation program including the development of the strategy, plans and resource requirements, and integrated program management, we are requesting $1,400,000 in FY 1987.

SUMMARY

In summary, the activities of the Department's transportation program cover a spectrum of projects structured to increase energy efficiency and reduce petroleum dependence in the transportation end-use sector. Although the program is focused on the transportation sector, the technologies under development for high-temperature materials, advanced propulsion systems, batteries, and alternative fuels utilization have a wide range of applications in addition to transportation.

That concludes my testimony, Mr. Chairman, and I thank you for the opportunity to appear before you today.

Mr. **Brown**. Thank you very much, Miss Fitzpatrick.

Mr. Lujan do you have any questions that you——

Mr. **Lujan**. Yes. I attended a briefing on the ceramic engine the other day that Garrett was having. They said that they would need about $50 million instead of the four which we proposed, and I came away wondering. One of the symptoms of that particular engine would be really not for vehicles but like arms for pumping of water and those kind of stationary things. Is it very difficult to transfer that technology from one to the other? The reason I ask that, I thought we had some diesel engines that we used to pump the water, and I'd rather think that the same kind could be used in a big truck or something like that. Am I mistaken? Couldn't these be interchangeable?

Miss **Fitzpatrick**. The Garrett engine is designed for an automobile. And we're working on another engine for heavy duty truck; that's the adiabatic diesel engine. There are many aspects of both programs which are interconnected, most especially, the use of high-temperature ceramics which will be required in both engines. Transferring an engine that's designed for an automobile to another use, such as pumping water, is certainly possible.

Mr. **Lujan**. How about vice versa? My understanding was that they felt pretty comfortable with using it for stationary purposes.

Miss **Fitzpatrick**. It's much easier to take an engine designed for an automobile and put it in a stationary, rather steady power supply use than it is to go the other way, because an automobile engine must not only be efficient and produce a sufficient amount of power but also must be able to deal with rapidly changing demands, quick startup and stopping. A stationary engine, for something like pumping water, doesn't have to do that. So an engine designed for an automobile is rather easily transferred to a stationary use, but vice versa can be very difficult.

Mr. **Lujan**. Would they need, then, additional money, if, as a matter of fact, the Garret seems to be that we can use it for stationary purposes? Is $4 million then enough to work into research the transcript of an automobile-type engine?

Miss **Fitzpatrick**. I think so.

Mr. **Lujan**. The real pay-off is coming and that's——

Miss **Fitzpatrick**. That's right. Well, the real payoff we're looking for, of course, in this program is an automobile engine with significantly increased efficiency and fuel diversity. That Garret engine doesn't need gasoline. It can run on diesel fuel. It can run on alcohol with very little adjustment.

The $4 million that we had proposed in our budget is to maintain one contractor team, either the Garrett team, or the Allison/GM team in testing component fabrication and design. We have completed two engine designs, the Garrett engine and the Allison/GM engine, and we are satisfied that those engines work and that they will meet their design specifications.

The problem now is how do you make the ceramic components for those engines, make them in a highly reliable way, and in an economical way. And that we don't know how to do yet. So it's the components that are the focus. And I certainly won't deny that if we put more money into it and have two contractor teams working we'll probably get the job done faster and with a higher likelihood of success. Our problem is that we've been asked to give a budget that will support the program goals and not go beyond what is needed to support the program goals.

Mr. Lujan. Basically, what you are saying is that both engines seem to work.

Miss Fitzpatrick. That's right.

Mr. Lujan. Have they run already? Is that what you mean?

Miss Fitzpatrick. They have been running. They haven't yet run, but they are scheduled to run this fiscal year, at their full design speeds and temperatures. The Garrett engine, I believe, is scheduled this month to be run at full design speed and temperature.

Mr. Lujan. And so the only problem is how to make those ceramic components that are reliable and long-life to them.

Miss Fitzpatrick. That's right. And to make them in a mass production mode. You see, we can make ceramic components if you almost hand make them, but how can you turn them out in the number that would be needed to go into commercial production? So we need really to work on reliability.

Mr. Lujan. Sorry, Mr. Chairman, for taking so much time. But when you say they'll be—the Garret engine, for example,—will be ready to run at full speed sometime through fiscal year 1986, that is for use in automobiles? Or for use in stationary——

Miss Fitzpatrick. It is an engine designed for use in automobiles. It will not be powering an automobile. It's being run on a test rig, but it is designed to run an automobile, and that is the purpose of that engine. And, as I say, it's much easier to use it in a stationary steady power situation.

Mr. Lujan. Is it a good idea for us to continue with it until it gets into automobile capability? Or that in private industry it can be done, maybe not easily, but——

Miss Fitzpatrick. We are continuing the work since the design work, we think, is completed. We have a successful engine; two successful engines. The next step is, as I say, the component fabrication step. So we are continuing that, and industry is very interested. They have increased their cost-sharing, and we hope to see them continue to increase their cost-sharing.

Mr. Lujan. I am sorry to ask a question again, but I'm not quite sure of the answer. So you have the two engines that are——

Miss Fitzpatrick. That's correct.

Mr. Lujan [continuing]. Designed to do what they were originally hoped they would do. That is, work in an automobile.

Miss Fitzpatrick. That's right.

Mr. Lujan. Thank you.

Mr. Brown. Mr. Packard.

Mr. Packard. Thank you, Mr. Chairman.

Miss Fitzpatrick would you review with me one more time—I'm sure your statement did it, but it was more in dialog—now I'd like, just specifically, now which projects are we discontinuing that are not completed? Which ones are we completing? I think I understood the Stirling engine is completing in a few months.

Miss Fitzpatrick. Yes.

Mr. Packard. Those two things particularly now.

Miss **Fitzpatrick**. We are completing the Stirling engine project, through the testing of the prototype, which we expect to have finished in April. We would not propose building more engines of the Mod II design or doing further testng on it. We have run the Mod I engines of the Stirling model about 14,000 hours—or will have run it that long by the close of this fiscal year. We have a great deal of test data and understanding of how that engine is performing which is available to the industry.

We have made the Mod I engine available to John Deere and General Motors for them to look at, and they did not indicate that they are willing to pick it up for further development. We have also made the Mod I engine available for stationary applications such as water pumping and electrical generation. The Army has asked to take one because they were very interested in using it on a mobile field generator set. We think that the Stirling engine is very well adapted to stationary applications.

Mr. **Packard**. More so than novelty?

Miss **Fitzpatrick**. Oh, yes. It does not handle power demand—changes in power demand—very well, and that is the difficult thing about an automobile engine.

Mr. **Packard**. And the projects that we are discontinuing, that we've not completed yet, are there any?

Miss **Fitzpatrick**. We have tried not to drop a project before coming to some rational point of conclusion. It's true that we won't be able to carry out all of our planned development as rapidly as we would like to. For example, with the ETX-II propulsion system, we are not proposing that we continue with the component development in that. We really think, actually, that industry is capable of carrying that on. We have a completed design—and also what that really needs—that complete system really needs its power source, the battery. And we are looking to the sodium-sulfur battery to supply power for that and that we are carrying on development of that battery. So there is a kind of synergism, waiting for one part of the system to catch up to the other.

We are continuing work on the adiabatic diesel engine. That is not being stopped. We are not really stopping any program except the Stirling engine program.

We're not proposing anything for a complete stopping except, excuse me, there are also a couple of the battery types that we are not proposing that we work on further. We will continue the zinc-bromine battery, as I said, the sodium-sulfur battery, and some of the advanced lead-acid battery designs. We would continue working with the nickel-iron battery as part of the dual-shaft electric propulsion system, a contract with Eaton, that we'll be continuing. The battery we think is about ready. It's simply a matter now of integrating it with the propulsion system. The iron-air battery has a number of problems with it. The nickel-cadmium battery is quite expensive and simply loses out on the economic's side, so we've moved that to a lower priority.

Mr. **Packard**. How do you articulate your R&D work with the commercialization of it once you've come to a point where it is economically feasible and has some commercial application? How do you articulate that into the private sector?

Miss **Fitzpatrick.** We try to start our R&D program, from its very inception, in cooperation with industry. We consult with industry when we plan research. We don't start out on a project unless industry has told us that there is a need for what that project is designed to deliver.

We assure that they are sincere in their expressions of need by entering into cost-share contracts with industry. So it's not just our money, it's private sector money, that's going into the development. This not only assures that we are doing something that somebody cares about on the commercial side but also that they already have, because they are participating in the contracts, they already have the information that is being developed by the research. They not only have the information, but their people are actually working on it, have hands-on experience, and are gaining the knowledge as fast as we are.

There is a continuum of phasing out the Federal funding and phasing in increased industry work. At some point, the contractors generally like to say, "We would rather proceed on our own because we are approaching now proprietary product development information." As long as the Federal Government is involved that information is public, and so there is a kind of natural transition.

There is always a certain tension where we think we've done enough, and they don't think we have. I think, as long as both sides are a little bit disgruntled, perhaps we've hit the happy medium. But, we do try very hard to integrate industry into our research from the planning stages all the way through each phase of the development.

Mr. **Packard.** The Stirling engine—has there been any interest from foreign countries or foreign governments on the Stirling engines?

Miss **Fitzpatrick.** The basic engine design is actually being used in this country under license from United Stirling of Sweden, so it's really originated there. We have had some interest from the Chinese government. I believe they are interested in water pump type applications. And I understand, also, that there is a consortium being started between a university and the main contractor, Mechanical Technology, Inc., for commercial development of the engine.

Mr. **Packard.** What promise has your research shown, thus far, on the ceramic work you've done thus far on engines?

Miss **Fitzpatrick.** We are very enthusiastic about the potential of ceramics in American industry. As I mentioned earlier, ceramics are absolutely necessary if we are to have successful high-temperature, very efficient transportation engines for both automobiles and trucks.

The key to the efficiency in these engines is that they operate at temperatures above 2,000 degrees Fahrenheit—say in the 2,400 to 2,500 degree range—and that they be able to recycle their waste heat back into the engine instead of cooling the engine through a radiator system. Metals are not sufficient to handle that. All the metals we have would melt at those temperatures, therefore, ceramics are absolutely essential.

We think that we are making great progress in the design of the material itself. What chemicals do you put into that material in order to make something that will withstand the temperatures and the stresses that are in the engine? And then how do you handle it? How do you fabricate the components?

We are learning a great deal more about testing and standardization of materials. We are sharing that information with industry, and in the last year or two we have had very substantial increase in industry interest in ceramics. We have had companies increasing the size of their own research programs and companies getting into the field that weren't in it before. So we've been very encouraged about the progress.

Mr. **Packard**. And how much longer do you think we will be involved in the ceramic research before it is taken over essentially by private sector?

Miss **Fitzpatrick**. That's very difficult to say because, I think, ceramics are one of those fields where the potential is almost—it's very hard to define—it's very large. And the more we learn really about the basic behavior of the materials—and I'm talking about how do the atoms themselves, I'm down on the atomic level—how do those atoms interrelate? How do the surfaces behave? It's going to be years before we get past the basic—where there will be valuable basic work—that will be appropriate, I think, for Federal involvement.

Ceramics really are a field that is drawing interest and funding from a number of areas, not just in the Department of Energy, but in other areas of Government. We do have a coordinating committee that meets regularly to make sure that the work being done in different places is not redundant and that people are learning from what is being accomplished in other places.

Mr. **Packard**. I would have to assume that our space program has a great deal of research being done on ceramics.

Miss **Fitzpatrick**. Absolutely.

Mr. **Packard**. Is there a transfer of technology there?

Miss **Fitzpatrick**. Yes, there is. NASA's part of the coordinating committee.

Mr. **Packard**. There's a glaring void in all that we are doing in this area and that is new starts. Have we simply dismissed the potential of new starts in our research in energy?

Miss **Fitzpatrick**. That is a void, Mr. Packard, and it's distressing.

Mr. **Packard**. It's primarily an economic issue.

Miss **Fitzpatrick**. It is a budgetary issue, yes.

Mr. **Packard**. That's all I have, Mr. Chairman. Thank you.

Mr. **Brown**. Thank you, Mr. Packard.

I'm going to recognize Mr. Lewis at this time and also ask him to preside for a few minutes while I have to take a necessary absence, and I'll be back very shortly.

Mr. **Lewis**. OK, Mr. Chairman.

Mr. **Brown**. Can you carry on?

Mr. **Lewis**. I'll do my best.

Miss Fitzpatrick, in your opinion, what would happen if the Stirling engine program was terminated this time?

Miss **Fitzpatrick**. We now have the Mod I engine. I believe we have built seven engines which will have run for a total of about 14,000 hours under test conditions at the end of—if the program were terminated as we propose—so we have a great deal of data on how that engine performs.

We have built and are testing the prototype Mod II engine. The prototype testing will be completed in April of this year. We would have that engine, plus all of its test data, available to industry. I think that that is enough information and hardware so that industry, if it's interested in developing this engine, would have the base that they need to proceed.

Our problem with the Stirling engine is, basically, the purpose for which we are being asked to develop it, and that is as an automotive engine.

We think it's an excellent engine for other purposes. It does not respond very well to demands for power acceleration. It does very well—it's a very efficient engine—if you use it in an application where it simply runs steadily, and it doesn't have to speed up or slow down, for example, pumping water as an electric generation.

I mentioned that the Army is very interested in using it on a field generator kit set. We are using it for residential heat pump. We have a program with the Gas Research Institute in which we are developing the Sterling engine on a heat pump. We are using it also on our solar program as the heat engine and electrical generator on a solar dish, and that looks as if it's very promising.

All of these are applications where the engine simply gets up to speed and runs and runs and runs. It's very efficient and very promising. We have not had any particular interest from the transportation industry in developing the Sterling engine for an automotive propulsion system.

Mr. LEWIS. Do you think there's any reason to look at research at low revolutions per minute or low speeds, in order to provide more torque to the engine to quicken acceleration, or do you think this is something that private sector should pursue on its own?

Miss FITZPATRICK. We think that that's something that the private sector now has enough information to pursue if it interests them. They have other alternatives that are coming along. We've talked a little about the automotive gas turbine engine, and they apparently would like to continue with those alternatives instead of trying to make the Sterling engine into something that it isn't now.

Mr. LEWIS. The answer you're giving shows that the engine has the same characteristics as the Wankle engine, the engine used in the Mazda, things of this nature that——

Miss FITZPATRICK. It can readily——

Mr. LEWIS. Automotive interests would be limited, and we'd have to more or less look for a place to use the engine rather than have the engine as a more universal engine.

Miss FITZPATRICK. That's true. It apparently isn't going to be or isn't ready yet for automotive applications. As I said, we think it's a very useful engine for other stationary, steady-state applications.

Mr. LEWIS. In your discussion with Mr. Packard on ceramics, are you looking at the $4 million—that budgeting the 1987 budget—to continue procurement from Japanese? Or just how is that money to be used?

Miss **Fitzpatrick**. No. That would be used for components for American industry, excuse me, American industry component development and fabrication.

It's true that we have obtained some component parts, principally the central rotor of the gas turbine engine, from a Japanese manufacturers; and we also have some rotors from American manufacturers. The Japanese rotor has been tested and run in the engine, and it performs rather well. We haven't yet completed testing on some of the American rotors. I might point out, by the way, that the Japanese were quite willing for us to have that rotor because they don't have an engine like we have to test what the rotor can do. There's a little bit of synergism going on.

Mr. **Lewis**. Are you privy to any of the information as to the temperature limitations of some of their rotating ceramic machinery at this point or——

Miss **Fitzpatrick**. Our engines are designed to go—I believe the Garrett is at 2,400 degrees Fahrenheit and 100,000 revolutions per minute. Is that correct? 25, the Garrett is 2,500 degrees Fahrenheit. The Allison/GM engine is 2,400 degrees Fahrenheit and 80,000 revolutions per minute. The stresses on that rotor at 100,000 revolutions per minute are immense, and that is why that is a particularly crucial and difficult component to fabricate. Also, the engine goes from ambient temperature to about 2,000 degrees in about 4 seconds. So the thermal stress on the ceramic parts is also immense.

Mr. **Lewis**. Does the automotive gas turbine engine rely on ceramic components that are supplied specifically by Japanese companies?

Miss **Fitzpatrick**. No sir. The ceramic components and the engine itself are American made. There is that rotor that we have been testing that is Japanese made. We also have American made rotors.

Mr. **Lewis**. Any further questions, Mr. Packard?

Mr. **Packard**. Thank you. I would like just to pursue one that I didn't pursue, and that is new starts. I just asked a question and dropped it. Are there some projects that are on the shelf, where you would like to see some sponsorship by Government funding, for new starts that you think have greater potential than what we're now doing?

Miss **Fitzpatrick**. We have included in our budget request, we think, the projects that have the greatest potential to answer the country's needs of getting more efficient transportation systems and getting off our dependency on petroleum. Those are absolutely the top priorities.

There would be some—if we had resources available—certainly there are some other tasks that we would like to pursue. But I'd have to say that they are lower priority, either because they are less promising, or because the time to achieve them is much more long range. So we have aimed at the most promising technologies.

I think that the adiabatic diesel program, which would provide a heavy duty large truck engine, is relatively new. We are really in the fairly early stages of that. It's already enjoying some spinoffs. Some of the components and coating work that has been done on thermal coatings is already being picked up by industry to be used in present engines, and they're very hopeful that that will be successful. So the adiabatic diesel engine is itself a rather long-term project and still in its early stages.

Mr. **Packard**. Thank you.

Mr. **Lewis**. Miss Fitzpatrick, what do you envision as any follow-on activities, or what are the follow-on activities you envision for the Gas Turbine Program?

Miss **Fitzpatrick**. We are going to continue with the component development, using the engines that have been built, putting components of different materials and fabrication techniques into those engines, and running them at speed and temperature to see how they hold up. We feel that that is the next step in that engine development, and we have enough money in the budget, $4 million, to carry on that work with one contractor. We would expect some cost-sharing by the contractor.

Mr. **Lewis**. How about——

Miss **Fitzpatrick**. Excuse me. We also have, under our Advanced Materials Program for which we have $6.5 million, a great deal of work on the basic materials of ceramics. How do you design the component? How do you test it? So that is feeding right into both the Adiabatic Diesel Program and the Automotive Gas Turbine Program.

Mr. **Lewis**. So are you saying then that there are some generic types that the ceramic program could use for other than the gas turbine engines?

Miss **Fitzpatrick**. Yes, sir. Yes, sir. We are finding that we expect that ceramics will be useful anywhere where you need high temperature and resistance to corrosion—everything from propulsion systems, to solar collectors, to heat exchangers and heat recuperators, and industrial applications, very wide application for ceramics.

Mr. **Packard**. One additional question, Mr. Chairman.

We haven't discussed or asked much on electric engine potential and electric vehicle potential, and we've obviously dealt with that off and on since the automobile. What is the potential there, in your judgment, in terms of maybe an alternative to the combustion engine?

Miss **Fitzpatrick**. We think the electric vehicle has great potential to achieve our goals. It's very attractive because, obviously, it's a nonpetroleum propulsion system. Not only that, but typically you would expect that electric vehicles would run during the daytime and be charged at night off of the utility system. This means that utility systems themselves would be able to operate more efficiently. It's a form of load-leveling for utilities.

Obviously they are clean, quiet, and have other nice amenities. Our problem has been how do you get them to run with a range that people will find acceptable? If the battery is going to die after 30 miles people aren't going to be happy with that.

Our long-term goal is to develop an engine, I should say a propulsion system, with a battery that would have a range of 200 to 300 miles. We can now run, say, 60, 80, perhaps even 100 miles, on the lead-acid flow battery that we're testing now. The sodium-sulfur battery, we expect, would deliver four to five times the energy capacity of the batteries that we have available to us today. And that is why we are so enthusiastic about the sodium-sulfur battery. We think that it would provide the power capacity—the energy capacity—that we need in order to achieve our goals.

Mr. **Packard**. You're talking about a radical change, of course, in our whole automobile industry. Has there been very much commercial interest in this old/new approach?

Miss **Fitzpatrick**. Yes. Absolutely.

Mr. **Packard**. Not a new, but I mean different approach.

Miss **Fitzpatrick**. No. The General Motors is heavily involved. Ford is involved. Battery and electronics component's manufacturers are in it, Eaton, Eagle Picture, General Electric. There is an organization, called the Electric Vehicle Development Corp., which is made up of, I think, about 50—mainly utilities—who are interested in the development of the electric vehicle. There are test fleets operating around the country which are using the product improvement results which are coming out of our programs and testing them and letting us know how they work. There is a great deal of private investment that is going into this, and I think that the potential is there, and I think that we are on track to achieve it.

Mr. **Packard**. What reaction are you getting on that concept from the oil industry?

Miss **Fitzpatrick**. I don't know, it's just—they haven't sent us any money, but they haven't tried to stop us either—as far as I know.

Mr. **Packard**. Thank you. OK, Mr. Chairman, that's all.

Mr. **Lewis**. Thank you, Mr. Packard.

Now, Miss Fitzpatrick, how does your 1986-87 budget compare to your original plan for ceramics?

Miss **Fitzpatrick**. We had originally asked for about twice as much in 1987 before Gramm-Rudman was passed.

Mr. **Lewis**. The percentages don't work like that. You don't get cut half, but why was it reduced that much?

Miss **Fitzpatrick**. Frankly, that's how much we were given to work with. And what we tried to do was maximize. We were within the total amount. We made the choices about what was to be done with it, and so we tried to pick out the most promising technologies and the best way to use that money.

Mr. **Lewis**. Assuming that you are below the scheduled funding now—which apparently you are—what is not being done? And who is going to pick up the slack?

Miss **Fitzpatrick**. We will not be able to proceed with two contractors on the development of the components and fabrication in the automotive gas turbine engine. With substantial cost-sharing by one or both of the contractors we could do more than—or I should put it the other way around—the more that they are willing to cost-share the more we can get done with the $4 million that we are proposing.

We have reduced—slowed down—our work in ceramics under the Advanced Materials Program—somewhat slowed down. We think we are still on target to work with industry and respond to their needs. As I say, they are becoming much more interested and, to some extent, are playing a little bit of catchup in getting their own capabilities up to speed with what we know how to do.

We are also going to reduce—actually zero out—our support of the Electric Vehicle Test and Evaluation Program. I mentioned that there are a number of private entities around the country who are operating electric vehicle fleets. They have been receiving some support from us in collecting and maintaining their data bases and exchanging that information. We will not be doing direct funding for that. However, one of the main costs that we had in the electric vehicle area for technology transfer was that we sponsored a major conference each year. The private sector is itself sponsoring a conference—major conference—here in Washington—an International Electric Vehicles Conference— and they are paying for it. So there has been a transfer of that burden to the private sector, and they have picked it up quite willingly.

There are a number of other areas, really, in all of our program areas where we could do more. And I won't pretend that there isn't useful work that can be done. We are simply trying to meet the goals that have been established and do our bit on the deficit reduction which we think is also very important.

Mr. **Packard**. Well, let me carry along with what you were talking about, Mr. Lewis, for a minute. Did I understand then that your area is sustaining about a 64 percent decrease from 1986 budget levels?

Miss **Fitzpatrick**. That's true.

Mr. **Packard**. Which is obviously a greater proportion of the budget reductions, percentage-wise, than many of the other—most of the other—departments are being asked to sustain. Is there a reason why your area and department has been called upon to sustain higher levels of deficit reduction than others in energy or other departments?

Miss **Fitzpatrick**. No sir, not that I know of.

Mr. **Packard**. The High Temperature Materials Labs are zeroed out. Where are we at on that program?

Miss **Fitzpatrick**. The funding that has already been appropriated will complete construction of the laboratory. It is scheduled to open early in 1987. The money is also available for equipment, and therefore, we would not, under any circumstances, have been planning to ask for money for construction and equipment. The operating expenses from the department will be coming out of the Office of Energy Research.

The work that will be done in the laboratory is quite broad-based. As I mentioned, the high-temperature materials have applications well beyond the transportation area, and therefore, it was thought better and more appropriate to fund it out of Energy Research than our budget. And it's also a User facility, which is one of its unique values, and so some of the money to support that facility will be coming from the industry people who come to use it.

Mr. **Packard**. Has this stringent budget request affected the personnel in your department?

Miss **Fitzpatrick**. Yes. We will have a reduction in FTE's—I think it's from 35 to 22.

Mr. **Packard**. Is that going to be done by attrition?

Miss **Fitzpatrick**. We would hope mostly by attrition.

Mr. PACKARD. I think you'd know that, at least, those of us who still remain here in this hearing feel strongly also about the deficit reduction.

Miss FITZPATRICK. Yes, sir.

Mr. PACKARD. And applaud you in your efforts, at least I do, applaud you in your efforts to meet the bench marks that you've been asked to meet. They are rather stringent. And I think, at least I feel, that it's going to take this kind of budgeting process at most levels, if not all, in order to achieve the goals that we are seeking in terms of deficit reduction. I appreciate your efforts.

Miss FITZPATRICK. Thank you, sir.

Mr. LEWIS. Miss Fitzpatrick, how are your programs in ceramics R&D coordinated with other agencies or departments?

Miss FITZPATRICK. We have an interagency materials coordinating group which meets regularly—I believe it's every 2 months—every 2 months. And this is a government-wide interagency group, so they share everything that they're doing, what their plans are, what their achievements are, and keep everyone up to speed on the various activities. We also have a group that meets within the Department of Energy because there are several areas, different parts of the Department of Energy, that are working on materials and ceramics.

Mr. PACKARD. Let me ask one other thing that came to mind. These budget bench marks that you have been asked to meet reflect the President's budget proposal, I presume.

Miss FITZPATRICK. Yes, sir.

Mr. PACKARD. If the Congress, by choice or by an action, moves to a sequestration how will that affect your budget figures?

Miss FITZPATRICK. You mean a sequestration of '86 funds?

Mr. PACKARD. No. We're talking about '87 budget figures aren't we?

Miss FITZPATRICK. Oh, I see, later on. Yes. Yes. You mean the 10 or is it 15 percent sequestration that would take effect automatically under Gramm-Rudman?

Mr. PACKARD. Yes.

Miss FITZPATRICK. I'm not sure actually. Can I answer that for the record and see whether that——

Mr. PACKARD. You're talking about a 64-percent decrease here.

Miss FITZPATRICK. That's right.

Mr. PACKARD. I think this is because of the prioritization process that the President has included in his own budget proposal. Sequestration, of course, is across the board, equal cuts which would change that percentage figure.

Miss FITZPATRICK. That's right. The question is, what's the base for the sequestration?

Mr. PACKARD. That's correct. I'm not sure I know that either but——

Miss FITZPATRICK. I'm not sure anyone does.

Mr. PACKARD [continuing]. Whatever it is, I think, we could expect that it would be much less than the 64-percent reductions.

Miss FITZPATRICK. That's true. If the base is 1986 appropriation and the sequestration is 15 percent—I've seen figures, I'm not sure what it's supposed to be—but that certainly wouldn't amount to a 64 percent reduction.

Mr. **Packard**. Well, in that scenario, if you're going to look at that for the record and present some information—I don't wish to create labor for you—but it might be worthwhile to give us also your priorities if there were additional funds that you would have available—where those funds would tend to go.

Miss **Fitzpatrick**. Yes, sir. We can do that.

Mr. **Packard**. Thank you.

[The information follows:]

PRIORITY ACTIVITIES FOR ADDITIONAL FUNDS

Based on the scenario that the FY 1987 authorization is the FY 1986 appropriation less a 15 percent sequestration, the additional funds i.e., above the Administration's request for FY 1987, would be used to support the following activities, listed in order of priority:

Activity Title	Additional Funds ($000)
Program Direction (7 FTE positions)	$ 460
Advanced Ceramic Materials R&D	4,660
Electric Vehicle Laboratory Testing/R&D Management at INEL	825
ETX-II Single-Shaft a.c. Propulsion System	2,500
Adiabatic Diesel Technology	2,500
Automotive Gas Turbine Component Development	6,000
Vehicle Propulsion Technology Assessment and Transfer	1,500
Alternative Fuels Utilization	240
Capital Equipment for Advanced Materials Development	1,000
High Temperature Materials Laboratory	1,000
Subtotal	$20,685

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Automotive Stirling Engine Development (No funds were requested by the Administration in FY 1986, but were appropriated by the Congress)	8,000
Total	$28,685

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Mr. **Lewis.** Miss Fitzpatrick, what is the distribution for funding for advanced ceramic research in DOA and in the other agencies and departments?

Miss **Fitzpatrick.** Oh, could I answer that for the record, please, Mr. Lewis?

Mr. **Lewis.** Yes.

Miss **Fitzpatrick.** Thank you.

Mr. **Lewis.** Pardon.

Miss **Fitzpatrick.** Could I answer it for the record?

Mr. **Lewis.** Yes.

Miss **Fitzpatrick.** I couldn't give it to you off the top of my head.

[The information follows:]

FUNDING FOR ADVANCED CERAMIC RESEARCH

Estimated funding by government agency for structural ceramics in FY 1985, FY 1986, and FY 1987 is listed below:

Government Agency/Program	Funding ($ in Millions)		
	FY 1985	FY 1986	FY 1987
Department of Energy			
Conservation			
Transportation	17.9	18.7	11.7
Industry	1.7	1.5	.8
Energy Utilization Research	1.8	1.8	1.0
Fossil Energy	1.5	1.2	.9
Energy Research	4.6	4.5	4.5
NASA	5.4	4.5	4.6
National Science Foundation	3.6	3.6	3.7
National Bureau of Standards		2.2	3.0
Department of Defense			
DARPA	9.4	10.0	5.0
U.S. Air Force	4.7	4.7	5.0
U.S. Army	2.5	4.4	4.7
U.S. Navy	1.4	2.3	2.3
TOTAL	54.5	59.4	47.2

Mr. **Lewis**. That would be fine.

Are you all finished Mr. Packard?

Mr. **Packard**. For the fourth time I am finished.

[Laughter.]

Mr. **Lewis**. Thank you.

Mr. Streb, would you like to say anything? You tried but——

Mr. **Streb**. Thank you, Mr. Lewis. I've spoken through the Assistant Secretary here.

Mr. **Lewis**. How about you Doctor?

Dr. **Chiogioji**. No, sir.

Mr. **Lewis**. Well, thank you very much for your very fine testimony.

Miss **Fitzpatrick**. Thank you, Mr. Chairman.

Mr. **Lewis**. Thank you, very much.

[Witnesses excused.]

Mr. **Lewis**. Our next witness will be Daniel Roos, director, Center for Technology, Policy, and Industrial Development, Japan steel industry professor, Massachusetts Institute of Technology.

Well, Dr. Roos, am I saying your name right, sir?

Dr. **Roos**. Yes. You are, sir.

Mr. **Lewis**. Dr. Roos, your testimony will be made upon the written testimony and will be made a permanent part of the record.

STATEMENT OF DR. DANIEL ROOS, DIRECTOR, CENTER FOR TECHNOLOGY, POLICY, AND INDUSTRIAL DEVELOPMENT, JAPAN STEEL INDUSTRY PROFESSOR, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Dr. **Roos**. Thank you very much, Mr. Lewis.

[Chairman Brown returns.]

Dr. **Roos**. It is certainly a pleasure to appear before this subcommittee and to talk some about the auto technology program at the Department of Energy. But, as I indicate in my testimony, I would like to focus primarily on the overall situation of the U.S. auto industry, some of the long-term industry needs, and what the Federal role might be in addressing those needs.

To do that, I'd like to draw, to a large extent, on a large-scale study that has been underway for the last 5 years at MIT. Let me just take a moment and describe that activity. We've organized research teams in all of the major auto producing countries of the world to look at a series of issues revolving around the automobile of international importance. Once a year we then convene a group of about 50 senior officials from industry, government, and labor, roughly one level below CEO. So, for example, from the U.S. members of that group have included Diane Steed, the head of NHTSA; Michael Driggs, who at that time was at the Department of Commerce; group vice-presidents from GM, Ford; chief Wall Street analysts from the auto sector, investment banker, executive vice president of the UAW. The argue being that, if we get those individuals together with their counterparts in Europe and Japan, in an off-the-record setting, we can very much get a better feel and understanding for what some of the issues are that the industry faces. We have those discussions, however, with the benefit of the research that's been performed. So it's not simply an interesting discussion, but we hope it's going to enlighten some of these officials as to what policies they might pursue.

We did publish the results of that first study in this book, which I'm gratified to say "Business Week" named 1 of the 10 best books of the year, The Future Of The Automobile. And although we had planned to terminate the study, we had such encouragement from industry leaders throughout the world that we are now continuing this for another 4-year period.

A lot of my remarks are based on what we observed during the course of the study. My role in that study, and MIT's role, has typically been one of a neutral, trusted arbitrator and really catalyst to try and bring some of these issues forward in an objective manner.

Today, obviously, I'd like to take a somewhat more specific view of the industry from the U.S. perspective. If we look at the industry, in one sense, the news is very good; we had an industry that was mired in a whole series of crises—not only energy, but environmental, safety crisis, in the 1970's. And the statistics are very impressive between 1973 and 1985. The fatality rate per 100,000 miles of travel was cut 40 percent, emissions per vehicle mile from new cars reduced by 50 percent, and fuel efficiency of new vehicles were double. These are very real achievements which the industry can be proud of and which point to what the benefit of available technology can be to tackle clearly identified problems.

However, looked at another way, I believe there is real cause for concern. The American producers have been profitable the last 2 years, but there are a whole series of signs of significant international competition that should cause us great concern.

Imports, once again, account for over 30 percent of sales, and that's in spite of the increases in cost of Japanese cars as a result of the yen-dollar relationship changes. We're having fairly deep discounting by the American producers. The voluntary restraint agreement has been extended another year and still the import penetration continues.

Just last week Hyundai began selling cars in the United States. They are now the top importer in Canada much to everybody's amazement. They draw the Yugoslav's who entered the U.S. market this year. And it's not only the low end of the market. The over $20,000 vehicle is virtually a European monopoly at this point in time. And if one looks at the value—the dollar spent—as opposed to simply the percentage in terms of number of cars, that's a significant amount of money at a very significantly expanding market place.

The Commerce Department has estimated that, by 1988, 17 percent of the cars which have U.S. nameplates on the back will be imported vehicles simply putting the U.S. nameplate on; and of the remaining vehicles assembled in this country last year, 18 percent of those vehicles had foreign components, and one study has just indicated that that will increase to about 30 percent in the next several years.

We also now have a situation where all the major Japanese auto companies have either established, or announced plans for, assembly facilities in the United States. And the estimate is that, by 1990, we will have 1.5 million Japanese cars built in the United States.

The situation does not look like it will improve. There are other developing countries, Taiwan, Mexico, Spain, Brazil, and India who will be shipping considerable volumes of cars and trucks in both the built up form, and we're going to have equally large flows of vehicle parts. The Japanese certainly are moving up scale. This March, Honda will launch its new division, Akora, with two new cars, and the other manufacturers also are producing midsized, larger, more expensive cars for North America.

One could ask how the United States has been able to maintain profitability with this situation. The answer I'd give is a combination of protectionism, primarily the voluntary restraint agreement, and a number of cooperative joint agreements with Japanese producers—the GM/Toyota deal being a prime example—productivity improvements, and creative labor arrangements bringing down the break-even rate level and probably, most significantly, retention of the very profitable middle portion of the market place—the larger size traditional family car.

However, if one looks at the 1985 profits, which just came out in the last several weeks, I'd suggest that's an early warning sign of the fragile health of the industry, and those profits were significantly below 1984.

There's real cause for concern if one starts to add up numbers because we see that the United States is headed towards a situation of overcapacity, which is a situation that the Europeans have had for the last several years, which has had very devastating impact on their auto producers. You have the new Japanese, and I might add, Korean facilities, which are going into the United States and Canada, a Ford plant being built in Mexico, an AMC plant in Canada, the new GMC Saturn plant. You put all that together it's a 30-percent increase in production capability by 1990. You compare that with the growth of the market, which is at best 1 to 3 percent, and one sees you have considerable excess capacity—with the implication being lots of plants are going to close. That's good in a sense. On the other hand, it represents, in all likelihood, a loss of market for the U.S. producers.

In addition to that, the inevitability of an economic downturn and the decrease in vehicle sales causes great concern as to what's going to happen in the event that that downturn occurs—in all likelihood, further cutbacks in investment, employment, and a continuing downturn spiral.

The obvious question is whether there's a way out of this path which can generate new wealth for our country rather than simply protecting activities which are not internationally competitive. I certainly don't pretend to have a definite answer. But I believe, if a way exists, it must be along the path of applying new technology to the products and, in particular, to the production process. Technological leadership will play a significant role in determining who the winners and the losers are, both from company and country points of view, in this international competition.

Investment and technology has always been the historical path for success of U.S. industry and as much evidence that the domestic auto industry is aware of the need to move as rapidly as possible. The Japanese and the Europeans certainly are aware—particularly the Japanese—they see this as the way of the future, and they're investing heavily in new technologies and automated processing. Regaining world leadership in the auto industry, even by playing to our strengths, will not be easy.

There are some optimistic signs if one looks at the U.S. Honda plant and the GM Toyota plant. The quality of the product being produced is equal to Japanese, as is the productivity, and I would suggest that that clearly demonstrates that the United States can be a world class manufacturer if they adequately utilize both new technologies and human resources.

Now what is the relevancy of this to the overall Government and Federal programs in the area of auto technology? I'd suggest, without in any way criticizing the technical accomplishments of existing auto technology activities, that they are largely focused on the issues of the 1970's—particularly in the area of energy efficiency. And while energy crises may recur in the future, and I'll talk about that it a moment, I would suggest there are more pressing problems where Government technology programs might be useful.

If we look at the Government activities, unfortunately, there's a great deal of fragmentation in the auto sector—not just in technology—where DOE, Department of Commerce, EPA, NHTSA, trade representative, NSF, even DOD are all involved. However, there is no clear focus, no agreement on objectives, the policies are generally short term, very domestically oriented, and sometimes conflicting, and unfortunately, we lack a long-term strategy that recognizes the realities of current and future international competition. If we had money and time to pursue many goals at once this might be fine, but unfortunately, we don't have that—as we are all aware.

So what can we do? And I have a few suggestions. First, that we should acknowledge our hard-won successes in the areas of energy efficiency, air quality, and safety were possible because a large amount of technology was readily available to the autoindustry for incorporation into commercial products within a short time. If the industry had to start from scratch developing these things, such as electronics for electronic engine control, we would have had to either restrict auto use or accept dirty air and excessive energy consumption for a long time. There are many other examples, and that's enormously important and a real credit to the programs.

These problems are under control, but we can't be complacent about safety or sanguine that no future energy crises lie ahead. So a Federal role, I believe, must be to work with the motor industry and academic research centers to identify technical problems requiring long-term research of a more basic type which will allow us to make significant technical leaps when the next need arises. Very frequently we don't know when that need will arise. Now the research I'm proposing does not require development of expensive prototypes or other hardware. Therefore, even in an era of budget crises, we should be able to afford a reasonable program of research which gives us a cushion against further energy or environmental crises.

Second, and I'd emphasize the great importance of the coming battleground, the coming battleground for competitiveness and productivity is going to lie in the area of process and design technology. In our research at MIT we have concluded that over the next

20 years, all across the world, semiskilled labor, whether cheap or expensive, will rapidly give way to smart machinery as the key element in competitiveness. Thus, the issue really is not cheap Korean labor nor expensive American labor. Rather, the challenge is rapidly introducing and perfecting new generations of design and process equipment and the complex social systems that must accompany them. Also, as we change the manufacturing process it gives us an opportunity to rethink the whole design of the vehicle itself—of the product.

Now clearly, the major responsibility for this lies with the private sector—particularly with commercialization. However, there is an important role for the public sector since the private sector cannot be expected to assume all responsibility, particularly for generic research, and that role is to drive the frontiers of knowledge.

I believe the major justification and benefit for a federally sponsored autotechnology program should be to increase our knowledge base and intellectual capital. If we're to effectively compete in the autosector we must have a cadre of technically knowledgeable individuals in the public sector, private sector, and academic research community. The Federal Government can serve, and should serve, as a facilitator and catalyst to establish that intellectual infrastructure for appropriate technology deployment.

The question of bringing together Government, university, and industry to identify and overcome the major bottlenecks in technology deployment. However, unfortunately, at the current time, the relationship between those three parties are rather distant—probably a residue of divisive battles of the 1960's and the 1970's—in contrast to Japanese and European situation. We really need to forge an intellectual network between American industry, American Government, and the American university research system to make the best use of the limited research funds we have available. I get concerned sometimes that, as an academic, this is viewed as very abstract and pie in the sky, but I firmly believe that this is the most important thing that this country can do in terms of addressing the issues of international competition.

Now, it follows from this, also, that the Government has to be an intelligent participant in discussions and decisions about technology and the American motor industry. And unfortunately, just at the time that the trend is toward the increased importance of technology we see the Government systematically cutting back from its assessment activities in the autosector from the remarkable level of expertise it possessed at the time of the Chrysler loan. What I fear is a government uninformed about the situation and needs of its largest industry can do more harm than good in trying to help. We had many painful instances of this in the 1960's and 1970's which, unfortunately, we cannot repeat.

Let me urge, therefore, in your deliberations that you take a broad look at the whole picture of the role of the Federal Government for auto technology and the currently suboptimal relationships between Government, industry, and academic research. Our research activities at MIT, which look across the world at trends in autotechnology and support activities of other governments, may be of some assistance in such an inquiry, and we stand ready to help in any way we can.

In summary, the message I've tried to get across is—as this subcommittee is well aware—we are seeing a systematic loss of our mature and high technology industries to international competition. Certainly protectionism is not sufficient to reverse those trends and, in many cases, rewards inefficiency, which further weakens our longrun competitive situation. If we're to compete effectively we have to have a competitive advantage—I'm suggesting that as technology— and the Federal programs are very key in that.

Auto sector certainly has improved dramatically, in a relative sense, in the last 10 years. But unfortunately, that's not sufficient, in an absolute sense, in terms of what world competition is forcing upon us. The Government programs we have now don't reflect the realities of that international competition and need for consistent long-term policies which emphasize technology. The activity suggested should be part of a cooperative effort between public sector, private sector, and the research community that's oriented largely toward development of a knowledge base rather than specific hardware programs, and hopefully this can allow us to maximize the benefits that we will derive from our auto sector.

Mr. Chairman, thank you very much for inviting me today, and I'd be glad to answer any questions.

[The prepared statement of Dr. Roos follows:]

STATEMENT

By

Daniel Roos

Director
Center for Technology, Policy and Industrial Development

Japan Steel Industry Professor

Massachusetts Institute of Technology

Before

The Subcommittee on Transportation, Aviation and Materials

25 February 1986

Mr. Chairman, it is a pleasure to appear before your Subcommittee and comment on automotive technology research and development activities at the U.S. Department of Energy. To do this, I would like to examine the situation of the U.S. auto industry in world competition, to identify long term industry needs and to suggest a Federal role in addressing those needs. However, first, let me identify myself.

I am Director of the Center for Technology, Policy and Industrial Development at MIT. This Center is concerned with how government policy and new technology influence industrial development in an era of intense international competition. Of more direct relevance to today's topic, I am also Director of the International Motor Vehicle Program, a broad-based study of emerging technologies, organizational trends and international issues in the world motor industry. This Program, coordinated through our Center at MIT, involves the direct participation and financial support of all the major motor vehicle producing countries and companies in the world, including the United States government through the Departments of Commerce and Transportation.

A key activity of the Motor Vehicle Program is to bring together, in a neutral forum on an annual basis, senior industry executives, government officials, and labor leaders from all of the countries involved in the international motor industry. In these sessions, we have frank discussions of mutual problems -- sometimes very frank indeed! -- and my role is to be the neutral arbitor. However, today I'd like to take on a different role and focus on the status of the auto industry from a U.S. perspective.

Looked at in one way the news is suprisingly good. An industry mired in energy, environmental, and safety crises in the 1970s -- crises which threatened its long term survival -- has addressed its problems with considerable success. Between 1973 and 1985 the fatality rate per 100,000,000 miles of vehicle travel was cut by 40 percent, emissions per vehicle mile for new cars were reduced by more than 50 percent, and the fuel efficiency of new vehicles was doubled. These achievements are hardly cause for complacency, but they do show what can be accomplished when the industry applies available technology to clearly identified problems.

Looked at another way, there is cause for concern. While the American-based producers have returned to profitability in the last two years, the U.S. auto industry faces intense foreign competition.
Imports once again account for over 30% of sales, in spite of price increases of Japanese cars (resulting from a dramatic change in the yen-dollar relationship) and low financing rates or rebates for domestic cars. This month Korea enters the U.S. market, anxious to repeat their Canadian success, where Hyundai is now the leading importer. Import penetration is not limited to the small car segment and the low end of the market. The expanding luxury car market has become practically a European monopoly.

There are other causes of concern. The Commerce Department estimates that by 1988, 17% of the cars with U.S. nameplates will be imported vehicles, and the remaining vehicles, although assembled in the U.S., have a significant amount of foreign components (18% last year). In addition, all major Japanese auto companies have already established or announced plans for assembly facilities in the U.S., so that by 1990 approximately 1.5 million Japanese cars will be built in the U.S. (some on a joint venture basis with U.S. companies).

Furthermore, the import situation is not likely to improve. The entry of Korea and Yugoslavia into the U.S. auto market this year is not an isolated event. Other developing countries such as Taiwan, Mexico and Brazil will soon ship considerable volumes of cars and trucks in a fully built up form, and equally large trade flows in vehicle parts may emerge as well. As the Japanese establish U.S. assembly facilities for small cars, they will reorient their import strategy to a direct assault on the mid- and larger size vehicles, which are the remaining strength of the U.S. industry. The European producers who, like the Japanese, derive their major profits from the North American market, will export even more luxury and semi-luxury units.

With this multidimensional assault, how have the U.S. producers been able to maintain profitability? A combination of protectionism (the Japanese voluntary restraint agreement), cooperative joint venture agreements, productivity improvements and retention of the profitable middle portion of the market place (the traditional larger size family car) have been the primary factors.

However, an early warning sign of the fragile health of the U.S. auto industry is the decreased profits for 1985, despite healthy car sales. Furthermore, North America is headed toward a situation of overcapacity in auto production by 1990. The net effect of new Japanese and Korean facilities in the U.S. and Canada, a Ford plant in Mexico, an AMC plant in Canada and the new GM Saturn plant represent a capacity increase of almost 30%. The U.S. auto market will probably increase at a rate of 1-3% per year, so that an increase of 10-15% at most by 1990 is likely. It is quite possible, however, that some time in the next several years, there will be an economic downturn with an inevitable drop in vehicle sales. If the total market shrinks, it is easy to imagine the U.S. produced faction of domestic motor vehicle sales falling below fifty per cent. This will necessitate further cutbacks in investment and employment and may easily lead to a continuing downward spiral.

Is there a way out of this ratchet of decline -- a path which can generate new wealth for our country rather than simply protecting activities which are not internationally competitive? I do not pretend to have a definitive answer, but I believe that if a way exists, it must be along the path of applying new technology to the product and, in particular, to the production process. Technological leadership will play a significant role in determining which countries and companies are the winners in future international competition. This has been the historical path to success for U.S. industry, and there is much evidence that the domestic industry is aware of the need to move as rapidly as possibly. However, both the Europeans and the Japanese see this as the way of the future as well and are investing heavily in new product technologies and automated processing systems. Regaining world leadership in the auto industry, even by playing to our strengths, will not be easy.

There are some optimistic signs. Not too long ago, many people claimed it was impossible to transfer the Japanese production system to the U.S. because of cultural differences. We now know that system can be replicated. The Honda plant at Marysville, Ohio and the GM-Toyota plant at Fremont, California, to take two examples, are producing Accords and Novas (Corollas) with American workers at quality levels comparable to Japan. Equally important, the productivity of the plants compares favorably with similar plants in Japan. Marysville and Fremont clearly demonstrate that the U.S. can be a world class manufacturer, if the processes and human resources are properly organized and utilized.

Now, Mr. Chairman, what is the relevance of the U.S. government's automotive research and development program to this situation? Without in any way criticizing the technical accomplishments of existing auto technology activities, let me suggest that the government's research activities are focused primarily on the problems of the 1970s, particularly in the area of energy efficiency. While energy crises may well recur in the future -- a point I'll return to in a moment -- there are currently more pressing problems where government technology programs might be helpful.

Unfortunately, the government's overall activities bearing on the auto sector suffer from a lack of focus. In an age of extremely tight resources for government, Federal motor vehicle activities are spread among a number of agencies -- DOE, EPA, NHTSA in DOT, NSF, and even in DOD -- without any clear focus or agreement on objectives. Our auto-related policies are short-term, domestically oriented and sometimes conflicting. We lack a long-term strategy that recognizes the realities of international competition. If we had the money and time to pursue many goals at once, this might be fine, but I believe we do not.

What then can be done in this situation, given, on the one hand, the competitive dilemmas of our largest industry, and on the other -- the fiscal limits on government? Let me suggest the following:

First, we must acknowledge that our hard won successes in the areas of energy efficiency, air quality and safety were possible because a large amount of technology was readily available to the auto industry for incorporation into commercial products within a short time. If the industry had had to start from scratch to develop the electronics for electronic engine controls, for example, we would have had either to restrict auto use or accept dirty air and excessive energy consumption for a very long time. And there are countless other examples.

These problems are now under control, but we cannot be complacent about safety or sanguine that no further energy crises lie ahead. The Federal role, I believe, must be to work with the motor industry and academic research centers to identify those technical problems requiring long-term research of a more basic type which will stand in the way of our making new technical leaps when the need next arises. The research I am proposing does not require the development of expensive prototypes and other hardware. Thus, even in a time of budget crises, we should be able to afford a reasonable program of research which gives us a cushion against future energy or environmental crises.

Second, we must acknowledge that the coming battleground for competitiveness and productivity lies in the area of process and design technology. In our research at MIT we have concluded that over the next twenty years, all across the world, semi-skilled labor, whether cheap or expensive, will rapidly give way to smart machinery as the key element in competitiveness. Thus, neither cheap Korean labor nor expensive American labor is our real problem. Rather, the challenge lies in rapidly introducing and perfecting the new generations of design and process equipment and the complex social systems which must accompany them. These changes in the manufacturing process will also enable us to rethink vehicle designand develop new concepts that would not have been feasible with existing manufacturing techniques.

Clearly, major responsibility for technology development rests with the private sector, particularly with regard to commercialization of technology. But the private sector cannot be expected to assume all responsibility, particularly for generic research, that is not directly related to commercial products. There is an appropriate and important Federal role for the government to drive the frontiers of knowledge.

The major justification and benefit of a federally sponsored auto technology program should be to increase our knowledge base and intellectual capital. If we are to effectively compute in the the auto sector, we must have a cadre of technology knowledgable individuals in the public sector, private sector and academic research community. The government can serve as a facilitator and catalyst to establish the intellectual infrastructure for appropriate technology deployment in the auto sector.

Efficient, effective technology deployment involves government-university-industry collaboration in identifying key technological and organizational bottlenecks and jointly attacking them. However, at present the relations between the three parties are rather distant -- in part a residue of the divisive debates of the 1960s and 1970s. We need to forge an intellectual network between American industry, American government, and the American research university system to make the best use of the limited research funds which will be available.

It follows that government must be an intelligent participant in the discussions we should conduct about gaining technological advantage for the American motor industry. Unfortunately, at present the trend is in just the opposite direction as the government systematically cuts back its assessment activities in the auto sector from the remarkable level of expertise it possessed at the time of the Chrysler loan. What I fear is that a government uninformed about the situation and needs of its largest industry can do more harm than good in trying to help. We had many painful instances of this in the 1960s and early 1970s, which we cannot afford to repeat.

Let me urge you, therefore, in your deliberations on the future of the Department of Energy technology research program to take a broader look at the whole picture of American government support for automotive technology and the currently suboptimal relationships between government, industry, and the academic research system. Our research activities at MIT, which look across the world at trends in automotive technology and the support activities of other governments, may be of some assistance in such an inquiry, and we stand ready to help in any way we can.

My message is simple. This Subcommittee is well ware of the loss of both mature and high-tech industries to international competition. Protectionism is not sufficient to reverse the trend and, in many cases, rewards inefficiency, which further weakens our long-run competitive position. If we are to compete effectively, we need public and private initiatives which provide a competitive advantage. Federal programs are particularly important for the auto sector, since it is our largest industry and, therefore, has maximum impact and visibility.

The U.S. auto sector has improved dramatically in the past decade, and industry, labor and government can share in credit for the changes. Unfortunately, those changes are not sufficient to meet the intense competition of the nineties. Existing governmental programs do not reflect the new realities of international competition and the need for consistent long-term policies. Since technology will play a key role in the future, our public sector activities should include a technology component that is oriented primarily toward insuring our knowledge base rather than specific hardware projects. That activity should be part of a cooperative initiative between the public sector, private sector and research community to develop an appropriate technology deployment system which provides a competitive advantage to the U.S. auto industry.

Mr. Chairman, thank you for inviting me here today.

Mr. **Brown**. Thank you very much, Dr. Roos.

I might say that your testimony is excellent. It would be appropriate for the consideration of a number of other subjects which come before this committee involving technology in all of its aspects, but it is particularly appropriate to the particular problems that face us this morning with regard to the support for automotive technology programs in the Department of Energy.

Mr. Packard, do you have any questions?

Mr. **Packard**. Dr. Roos, in your testimony you did feel that we are probably not looking at the long-range picture, that you have some concerns about us being shortsighted in our efforts and, particularly as it relates to technology advancement, in preference to the short-term goals that we have. And yet, at the same time, in the early part of your testimony you mentioned that our research and development programs still are of the 1960's and 1970's generation. Is there a conflict here in your comments? And where should our moneys be going if not in the specific projects that we've discussed earlier this morning?

Dr. Roos. I'm not sure that there is conflict. The point I would emphasize is that if we really take a long-term look then we recognize that the issue of international competition is hugely important. And therefore, we should, to the extent possible, reflect that in terms of what we do with respect to technology; and if we are dealing with very, very scarce resources, then rather than addressing primarily what were the significant issues of the 1960's and 1970's—which were what I suppose I'd call the harmful side-effects of automobile use in terms of the environment safety and energy, those were the key issues—those continue to be issues today, but they are certainly not the key issues in terms of the industry, and it would be very beneficial—and I would suggest necessary—if we are going to preserve a significant domestic auto industry that we reflect in our Federal programs the realities of the current international competition.

Mr. **Packard**. Do you think that we would be more wise in stressing and emphasizing automation types of programs in our manufacturing plants relating to automobiles, or do you think that we ought to be project oriented, as we seem to be now, where we are looking at specific programs and projects.

Dr. Roos. Well, I think you still can be project oriented. But if one looks at the existing programs they all deal with product technology as opposed to process technology—process technology being the manufacturing aspects—and certainly both are experiencing technological leaps forward. But one could argue that the changes with respect to the process are significantly greater than the changes with respect to the product, and somewhat more of a balance might be appropriate in terms of the Federal programs which right now are so heavily oriented toward the product.

Mr. **Packard**. Do you think that other—that our foreign competitors—that their governments are doing more toward this upgrading of the process of manufacturing than we are here in this country in terms of actual dollar commitments?

Dr. Roos. They are doing several things. And the point I would stress is that I don't believe that the significant issue is dollars, even in an era of extremely scarce resources, but rather how those dollars are spent and also the deployment system that's established.

If one looks at the Japanese, it's an extremely tight coupling of industry, of government, and of university research community, and that's an extraordinarily competitive marketplace. One is able to keep that balance where you still have fierce competition in between companies, particularly with respect to the home market, and yet an overall coordination with respect to industry and national goals, and that, unfortunately, is lacking here. We just seem not to be able to relate the various sectors and to be able to utilize our expertise in the best possible way.

One can look at England, and England had an enormous amount of research and a tremendous number of inventions and innovations. But somehow they couldn't get their act together in terms of utilizing that technological edge in creation of new enterprises and putting all the pieces together. And I think that really is one of the key aspects of the Japanese success.

Mr. PACKARD. Do you see, Dr. Roos, a radical shifting and changing of the direction of the automobile industry worldwide in terms of technology, or do you see this being a very gradual transition from the traditional automobiles that we have known since—in my life time? Do you think that we'll see radical changes in the world market?

Dr. ROOS. One has to always be careful when one uses radical change, because it is a relative term. I'll answer that in two ways.

The vehicle that we drive 10 years from now, I think, fundamentally will be very similar in terms of the propulsion system and the appearance of the vehicle, but the way that vehicle is put together will have changed radically. So it will not be that apparent to the consumers. Certainly there will be new materials that will be used.

Probably the most significant change that is impacting both the process and the product is the introduction of microelectronics, computers, and information systems. The automobile, since it came on, has largely been impacted by mechanical innovations. But now, all of a sudden, this industry—which to a large extent was a mature industry from a technology point of view—is being impacted by electronics and computers. And if one looks at process control, you now have flexible manufacturing systems, automated systems—and those totally change the way cars are going to be produced—and that really is a radical change; and one sees it with respect to some of the projects being undertaken, like the Saturn and the Liberty projects by the U.S. companies. But it really is going to restructure how the whole industry works, the relationship between assemblers and suppliers, the whole way we think about putting a car together, and to me that suggests very radical change.

Mr. PACKARD. As foreign competition in the steel industry has emerged—and one of their advantages that they have had as they've built relatively new steel manufacturing plants in foreign countries—they have been able to implement the new technology, in terms of equipment and in terms of fabrication, and that essentially had some serious impacts upon our own rather staid, and obsolete in some cases, steel manufacturing plants here. Do you see now—as new countries coming into the marketplace in automobile manufacturing—a similar problem where they, Korea, and others that are now entering the world marketplace having a newer factory base, comparatively, just being able to implement new technology in the process of manufacturing compared to our old and perhaps outmoded manufacturing plants themselves—the equipment itself—and thus getting an advantage to the point that will have an ongoing and a deeper effect upon future world markets for us, and if so, what is the solution?

Dr. Roos. You posed several questions and let me try and address each of them.

The answer to the first is yes. I think it is a real concern. It's very interesting, however, to look at the Japanese situation because, to a large extent, the Japanese success was based not on technological leadership for technological innovation but more management organizational innovation of how the production process should work. However, over the past several years the Japanese have been making huge profits. Toyota is debt free. That money has been invested in technology. Now one—and since you ain't seen nothing yet—because now the Japanese are first coming on with the results of the investments that they've made in technology.

Now what can be done about it? It's very interesting. When we started our study everybody was saying, "Well, that system can't be transferred to the United States. It's all cultural differences. It works in Japan, but it won't work in the United States." We now see that it will work in the United States. The Honda plant, as I pointed out, in Marysville, which is staffed by American workers, which is not a high technology operation matches roughly the productivity of Japanese plants. We can do it in this country. It's organized by Japanese management, as is the GM Toyota plant. That plant in the United States will be bringing in automation over the next several years.

And that gets me to your other question, "What can we do about it?" What I argue we must do about it is make a serious commitment and investment to technology. That is, as far as I can see, the only area where we have had historically a competitive advantage in the past and where we can maintain that competitive advantage in the future. I think that's particularly true of the electronic technologies. And if we're going to continue to succeed as a nation we absolutely have to commit ourselves to make that investment or else we are simply going to see a continual erosion, not only of this marketplace, but the ripple effect of this industry. Every dollar invested in this industry has at least a dollar and a half of indirect impact on other significant industries in this country—steel and other material industries—you are well aware of that.

Mr. Packard. Mr. Chairman, one more question, if I may. I am well aware that I am over my time.

I just returned—this committee—from Japan and Korea a little over a month ago, and it became obvious that they are going to, Japan particularly, is going to redirect their emphasis in the automobile world marketplace into the midsized, midpriced, and larger cars. They have them there, in fact, they have very few small cars. They shipped them all here, and that was one of the surprises over there—that you don't see a lot of small cars in Japan—not like you do here. They have much larger, much more expensive, $20,000,

$25,000 cars on their highways. And they intend to capture a good deal of that marketplace here, and they are conceding, and they stated that they concede, the small car market to Korea and some of the newer countries that are coming into the marketplace. That will certainly put a great deal more pressure on what you indicated in your testimony as being an open market here—domestic marketplace—in the United States in the midpriced cars. European market has captured, according to your testimony, and has a monopoly on the higher priced cars, and the smaller priced cars the Asian marketplace has dominated. We're leaving open what we consider the midarea. That may change radically with the focus of their market projections. How will that affect the competitiveness of the United States?

Dr. Roos. I think it should be a real concern.

I mentioned Accura, which is the new line of Honda. The reason that it's a new line is that Honda wants it identified as a luxury, high priced product—as opposed to the Civic and the Accord—which have traditionally been more at the low end of the marketplace.

The direct competition that Honda points to is Mercedes and BMW, and they have made it very clear that that is a portion of the market that they want to target. That was done—those products were done—in cooperation with BL (British Leiland). So one has the benefit of some of the European technology and expertise being blended in with the Japanese manufacturing expertise, and one can only expect that they will be very successful in what they do.

Mr. Packard. Thank you, Mr. Chairman.

Mr. Brown. Mr. Lewis.

Mr. Lewis. Thank you, Mr. Chairman.

Doctor, your testimony indicates that you believe the Federal Government's automotive R&D programs are improperly focused. Would you be a little bit more specific, like which programs should we eliminate, should we eliminate the Stirling, AGT, electric vehicle, what have you?

Dr. Roos. It's a difficult situation. I think that when you start programs that are demonstration or development activities that they're started with an expectation of a viable product, and those things typically take a fair amount of time to develop. When you then have a situation, as is obvious here, of budget reductions, in a way you're caught—what do you do—between a rock and a hard place in a sense; because, if you continue the programs to the point where you get a product you've been looking for, you're potentially criticized because you're not focusing in on new issues and new problems. On the other hand, if you cut them off then people come in and say, "Well, my goodness, look at this. We've been working at this for 5 years or 6 years and now we have nothing to show for it." So it's very difficult.

The point I would make, and try to make in my testimony, is that hardware projects are always very, very expensive no matter what we do. And on the other hand, projects that are research projects but not involving development of prototypes—one can go a long way with a relatively small amount of money. And what I would argue for, I think political realism suggests that one is not going to arbitrarily stop a whole set of programs and start a new set of programs, but at least have more of a balance in what is currently being done.

The industry has just changed dramatically over the last 10 years. The problems have changed dramatically, but if one looks at the research activities of DOE they really haven't changed that dramatically. And one can raise questions as to, "Shouldn't there have been a little more responsiveness to the changing set of priorities?"

Mr. **Lewis**. Will you be specific and tell us what type of automotive research development programs that you would support.

Dr. Roos. Well, first, as I've suggested, I think that we should be concerned with the process side as well as the product side and a key there is the computer. And understanding the role that the computer plays, both with respect to the process and the product and I'm talking here of areas such as computer-aided design, computer-aided engineering, computer-aided manufacturing, robotics, flexible manufacturing, all of these things are having and will continue to have a significant impact on the auto sector. We have to continue to be concerned about basic research that goes into the product, processes such as combustion, understanding some of the new materials that are coming along, doing work in those areas becomes very, very important.

Mr. **Lewis**. Do you think that the research and development into ceramics technology is an appropriate role for the Federal Government?

Dr. Roos. Yes, I do.

Mr. **Lewis**. Where do you feel the break point is where private sector should become a partner with the Federal Government in order that the Federal Government should break away from this?

Dr. Roos. Well, I think the private sector ought to be a part right from the beginning. And one ought to have a better process of deciding what the priorities are involving private sector and research community right from inception so that you have the participation in setting some of the goals. This is certainly one of the things that the Japanese do extraordinarily well.

The requirement that the private sector put up matching funds is certainly a good "litmus test" in terms of how serious private sector is about certain areas.

I'm just thinking of an analogy that we had. Maybe I should mention it, because it proves several of the points that we've been talking about in the questioning.

Before directing the center, I was head of the transportation center at MIT, and we looked at the railroad industry, which in some ways similar to the auto industry, was an industry that did not—was somewhat inward looking—the technology was mature. It hadn't been using new technology, and the question was, "What should they do?" and "How should they do it?" And we put together a cooperative program of industry, Government, and universities.

And that happened 10 years ago where industry leaders talked about some of the things that were most important to them. There were projects that were funded at the Federal level, but then as they got very much into an operational stage they passed to the industry, and MIT was heavily involved in this. We did some of the development, tried it out at one railroad, then went and tried it out at five or six other railroads.

One of the most interesting things I found was in looking at the graduates from our program over the 10-year period prior to this research. None of them went into the railroad industry. Absolutely none.

Over the 10-year period that we carried out this program there were some 50 students who were involved in the program. More than half of those students then went and took jobs in the railroad industry and now, as I look around, they are all vice presidents, and some of them have gone into Government, some have gone to the supplier companies. And that's the point that I really wanted to get across—several points—that industry-government-academic community sat down, decided on priorities; priorities changed over the 10-year period. There were cooperative research projects that phased, but probably the most significant benefit was you wound up with 25 or 30 people who were well-trained, who understood the technology, who went on to play leadership roles within the industry. And those people never would have gone into the industry, and that was not a big bucks program, that was program that ran at a level of under $1 million a year, well under $1 million a year. It had really significant benefit. And that same sort of approach of cooperation and diffusion and deployment are really key.

Mr. **Lewis.** Thank you, doctor.

Thank you, Mr. Chairman.

Mr. **Brown.** You know, Dr. Roos, the fundamental problem that we're having in trying to develop and support legislation involving this business of maintaining the competitiveness of American industry is political and philosophical.

Why, for example, did the taxpayer's dollar go to fund research in automobile technology or steel technology or electronics technology when we have very large and historically profitable enterprises in these areas? And the trend is toward even larger—the last few years have been marked by mergers—leading to larger and larger concentrations of capital in numerous fields. Why should the taxpayer get involved in this? Why can't the market process do this? In effect, if the steel industry isn't sufficiently interested in its profitability let the steel industry wither on the vine and the capital and management and labor involved there move to some other area which is more profitable and, according to normal economic theory, therefore, making a bigger contribution to the national welfare.

You get involved in that kind of discussion?

Dr. Roos. Oh, all the time. Yes.

Mr. **Brown.** Well, I think you have to—we have to face it here.

Dr. Roos. Absolutely.

Mr. **Brown.** Because you see, 10 years ago we were trying to develop this beautiful philosophy you're talking about, joint industry-government cooperation. We've passed the Stevenson-Widler Act. We did a lot of nice things like that which are not going anywhere. All of these programs we're talking about today were passed 10 years ago, and they are not going anywhere—they're getting cut out. But we have to have some sort of a political justification appropriate to today's time.

Dr. Roos. In answer to your question, I think one answer is the degree of concern. And if we had a situation where, as the steel industry went off-shore, we simply moved on to other industries who have U.S. superiority—that would be fine. But we have a situation today where, across the board, we are being subjected to intense foreign competition, and that's true of our high-technology as well as our mature industries.

Certainly we're all familiar with semi-conductors and what's going on there increasingly with Japanese competition in the computer field, and I think we are seriously underestimating what the impact will be there. There's a student who's at MIT who's doing a doctoral thesis on this right now in the semi-conductor and computer industries, and his conclusion is that we have just totally underestimated what the impact of foreign competition is going to be. So we really can't take as a premise that we simply move on to other industries.

I felt, I was going to say interesting—maybe depressing a better word—brought along this week's issue of "Business Week" which is very relevant to the discussion today. It talks about the hollow corporation, a new kind of company evolving in the U.S. manufacturing companies, that does little manufacturing. They simply buy products manufactured by foreign companies and slap a U.S. nameplate on them. And here's good old free enterprise "Business Week" saying, "We've got to do something about this." And what they say is, basically, industrial policy is a dirty word. But, on the other hand, there has to be a public role in this.

And I think the answer to your question is that the play-out of the existing scenario is very, very scary in terms of this country. If one looks at what other countries are doing, they are making the sorts of investments that we're talking about. So just from the viewpoint of survival one can justify it.

Mr. **Brown**. Survival of what, Dr. Roos? These corporations find that it's profitable to put their capital overseas and take advantage of the technology, the labor base, other factors of production, are doing so and continuing to be profitable. The corporate system is global. The market is global. In effect, you're asking us to deny the validity of the corporate free enterprise system and its ability to adapt with what you're suggesting.

Dr. Roos. No, I don't think I am. Many of my remarks are the result of sitting down with CEO's who are pleading for a more level playing field—that there's a real danger, with respect to the corporations, but, I think, a much more significant danger to this country if we lose our manufacturing base.

Mr. **Brown**. What is the danger to this country?

Dr. Roos. The danger is that we start looking like a developing country in many ways. I mean, we have all the characteristics in terms of trade balance, of ownership of enterprises. 1.5 million Japanese cars being assembled in this country might be good from the viewpoint of supplying jobs to a number of people, as opposed to those cars being shipped from Japan, but it also is a little bit scary in terms of the significant ownership of resources, key resources, by foreign corporations.

One can argue that particularly in the auto sector, the industry has really been hit with the whole series of shocks, going back to the 1970's, and has responded extremely well. I think, to a large extent, the free enterprise system has worked. That's the reason that we have profitable auto companies today. They had the energy crisis, the recession, and the invasion of Japanese imports, but we're also talking a fundamental structural change.

Look at the Saturn project. The Saturn project, which represents a rethinking of the product and process, maybe will go online by 1990. When it goes online in 1990 maybe we'll produce half a million cars a year. By 1990 there will be 1.5 million Japanese cars being produced in this country. So then GM has to diffuse—if it works, and if it works by 1990—the results of GM's investment throughout the corporation. The point is that there's an enormously long lead time and an enormously great investment required of corporate America to catch up to the new international competition, and, I think, they're doing a very good job in many respects. The point I would make is they can't do it alone. The situation has changed so radically.

When you compare what one is asking the Federal Government to do, relative to the investment that's being made by corporate America, it's a relatively modest investment. What I was also arguing before was that, whatever was done, should be done with the support and acknowledgement of the private sector. It becomes very important in setting the priorities and the goals and the programs and the particular projects being carried out that the private sector play key roles in determining what those projects are. We've gotten ourselves into a situation where certain things were decided roughly 10 years ago, and then they develop an institutional life of their own, and it's very, very difficult to change and redirect.

If one had a more responsive process by which some of these priorities got set up with the private sector, with the research community playing an active role, then I don't think one would get into the squabbles and questions of, "Should they do this?" or, "Should we do this?" and, "How do we justify it?" I think one would find, as we did with the auto project, there's a surprising consensus. Whereas people thought they were adversaries, they really weren't, but it's getting them all together to agree on those joint goals.

Mr. Brown. You haven't totally resolved the problem. The automobile industry, as you pointed out, in the 1970's didn't feel that they needed any assistance of any sort. They didn't need research assistance, technology assistance, particularly they didn't need regulation that would lead them to higher factors of safety or fuel economy or environmental pollution. They resisted it every stage. They also just about went broke, at least Chrysler did, and the history is that they come in and want Government cooperation when they are about to go broke and face some catastrophe. That's not really a very good basis to establish a relationship.

What I would like to see is an enlightened recognition, on the part of the great corporate enterprise in this country, that we would benefit as a Nation from the kind of patterns that you've described. I don't really feel like continuing to butt my head up against a stone wall, to be honest with you, and I've been doing it for 20 years, and my head's getting a little soft up there. So what do we do to instill or encourage this recognition that our national survival and competitiveness requires some modification of the relationships that have existed in the past and requires it other than in a bail-out kind of a situation?

Dr. Roos. Well, I think you're quite right, Mr. Chairman, in your observations. Let me suggest that, when one does get some of the leaders to sit down together in a nonadversarial setting, that one can get a remarkable agreement on what has to be done. And I'm including labor in here as well as management; and I believe that that's the approach that one should follow, and do that at all levels. Do it at the most senior level, in terms of the CEO's and the heads of some of the Government agencies; and do it at a working level, in terms of some of the research people, and what the technology programs are going to be.

We seem to always get ourselves into these situations of pointing fingers and pinning blame. All of the observations you make are correct. But then, I'll sit down in the board room and listen to a similar set of allegations about the Government, and how they can't get their act together, and how they have all these conflicting short-term policies, and how we gear up for one policy, and the administration changes, and then all of a sudden we have a new set of policies. And can't we have some idea of where we're going and how we're going to get there? You're right and they're right.

I think until we have such an agreement, that's the thing I point out in my testimony, that still we are without a fundamental policy. We are the only country without that policy, and we're the country that both Europe and Japan are looking for in terms of their profits. That's where all the European/Japanese profits are coming from the United States. And so this marketplace is just so important that until we have a better idea of where we're going, how we're going to get there, and then a joint agreement that we're all going to work together on this thing, I think, another 20 years it's going to be banging your head. I agree with you.

Mr. Brown. I have no further questions. If any of the staff have any questions——

Thank you very much, Dr. Roos.

You haven't solved many of our problems, but you have illuminated some of them. Thank you.

We will have a second day of hearing on this subject on Thursday, at 10 a.m., in which we will hear some industry views. Maybe we can propound these questions to the industry representatives and see how they respond to it.

The subcommittee will be adjourned.

[Whereupon, at 10:52 a.m., the subcommittee was adjourned.]

FISCAL YEAR 1987 DEPARTMENT OF ENERGY AUTHORIZATION

(Transportation Programs)

THURSDAY, FEBRUARY 27, 1986

House of Representatives,
Committee on Science and Technology,
Subcommittee on Transportation,
Aviation, and Materials,
Washington, DC.

The subcommittee met, pursuant to recess, at 10:05 a.m., in room 2325, Rayburn House Office Building, Hon. Bill Nelson (acting chairman of the subcommittee) presiding.

Mr. Nelson. Good morning. The meeting will come to order.

I regret to say that our chairman's absence is occasioned by his wife being quite seriously ill, and so we will have to proceed this morning without Mr. Brown. Perhaps he will be available a little bit later on.

Today this subcommittee will continue hearings on the 1987 budget proposals for the Department of Energy's transportation program. Last Tuesday, testimony was taken from Department of Energy officials. Today we will hear testimony from those who are directly involved in various DOE research projects currently underway. Specifically, we will hear about the progress on the Stirling engine program, the automotive gas turbine program, electric vehicle battery development, and high-temperature materials research.

The budget proposals for 1987, reflecting 64-percent cut from the amount appropriated for this year, present us with some difficult decisions on the future of transportation research. This committee is not only concerned about looking at specific funding levels of the various programs, but also about assessing future research needs and opportunities, as well as the possible restructuring of DOE's transportation research program to meet the needs and the opportunities.

So we are most grateful for the witnesses who have agreed to assist the subcommittee today in these deliberations. May I turn to the ranking member, Mr. Lewis?

Mr. Lewis. Thank you, Mr. Chairman.

The testimony we heard earlier this week on DOE's transportation program was generally very positive about the success of these programs. I think we all agree that these programs have been useful and the contractors have done an outstanding job of meeting the goals of their programs. In a sense, they have now found that they are victims of the[illegible]wn success.

The administration proposes significant reductions in this area in view of the huge deficits we are facing. In the Gramm-Rudman mandate to reduce those deficits, it is obvious that we have to make some tough choices. It is not going to be enough this year to argue the benefits of a program. I think we have to ask the question, "How far must the Federal Government go in demonstrating a technology before it is reasonable to ask the private sector to pick it up?"

If the technology has merit and the private sector is interested in pursuing it, I think we are going to have to ask them to pay a larger share. We are all concerned with the problems of foreign competition, and I think we would all agree that we want a level playing field for our own industry, but we simply cannot respond to every threat of foreign competition by spending millions of Federal dollars to demonstrate every promising technology to the point where no risk remains for industry.

I know the choices we have to make will not be easy. Nonetheless, the responsibility is ours. I hope the testimony we will hear this morning will help us make some very difficult decisions.

Thank you, Mr. Chairman.

Mr. **Nelson**. Thank you, Mr. Lewis.

Mr. Nightingale and Mr. Goldwater. Please, if you will, proceed. Thank you for being with us.

STATEMENT OF NOEL P. NIGHTINGALE, DIRECTOR OF PROGRAMS, STIRLING ENGINE SYSTEMS DIVISION, MECHANICAL TECHNOLOGY, INC., ACCOMPANIED BY MR. GOLDWATER, VICE PRESIDENT AND GENERAL MANAGER, STIRLING ENGINE SYSTEMS DIVISION

Mr. **Nightingale**. Thank you, Mr. Chairman.

Accompanying me this morning is Mr. Goldwater, the vice president and general manager of the Stirling Engine Systems Division at MTI.

I have presented a full testimony for the record, and I would like to summarize that testimony for you this morning.

Mr. **Nelson**. We appreciate it.

Mr. **Nightingale**. I would like to touch upon the status of the ASE Development Program, discuss a few of the spinoff programs that are starting to evolve from our work, present you with some of the intelligence we know of the activity in Japan on Stirling development, and then touch upon a Stirling engine technology program which we feel will enable us to keep the lead in this valuable technology.

Just to focus my discussion around the two major goals of the work that we have done, which was to develop an automotive Stirling engine for you and our country, and to transfer that Stirling engine technology to the United States and give us a lead in that, this is a picture of the Mod II. It is in fact at test now, and I thought you would appreciate a three-dimensional photo like that.

This is a picture of the Mod II which has been designed specifically to fit inside a General Motors Celebrity, which is an A-body, front-wheel drive car. The radiator there is in the front, and that's how the installation looks under the hood of a car.

The status within the program is that the Mod II engine design has been completely designed, hardware has been manufactured, and we in fact—as we promised you last year—started the test in January 1986. The Mod II is projected to give us 41 miles per gallon combined, and an acceleration of from 0 to 60 miles-per-hour in 12½ seconds.

If I can dwell a moment on the mileage figures, that graph is a picture of the mileage that we obtained in our earlier testing with the Mod I engines in the program, where we were obtaining about 24 miles per gallon. After some testing at the GM lab we were able to incorporate some of the Mod II technologies into that engine, so that we managed to increase that mileage up to 28. That gives us the confidence that our Mod II will, in fact, meet the 41 miles per gallon projection that we are using, simply because the upgraded Mod I to this date has reached about 22 percent above the IC.

Another point about this curve is, you can see how the industry has done in terms of their mileage. The Celebrity with the spark-ignition engine in it has 31 miles per gallon, whereas older cars like the Spirit were as low as 23 miles per gallon. You can see how the competition has certainly improved as well.

The next slide, you cannot talk about mileage without really addressing acceleration or "performance" as we like to use it, vehicle performance. The major criteria used to measure performance is the time taken to accelerate from 0 to 60 miles per hour. Earlier in the program, certainly one of the criticisms against Stirling engines was that they were heavy relative to their power size, and that certainly showed up in these types of data—the acceleration times of 28 to 26 seconds. It wasn't until we got into microelectronics and into the control system of the Mod I and the Mod II that we were able to bring that acceleration down to around 16 seconds, and so we feel fairly confident that the Mod II will perform as we have projected and be competitive with the spark-ignition engine.

Another major point relative to our status is that we have maintained, at the will of Congress, the schedule, and the technical milestones that we have promised you over the past. The program is on schedule to be completed in fiscal year 1987. To emphasize that fact, I present you with a schedule which I presented at my testimony last year in which I indicated that the engine would be at test this year. I think this graph also shows you that all of our efforts from here to the end of the program will be devoted toward developing the Mod II engine and demonstrating the program goals in September 1987.

We continue to also develop valuable life and reliability off the Mod I engines in the program. I think that life and reliability are important parameters as far as industry is concerned.

The next graph shows the increase in engine hours that we have been able to obtain off the Stirling. These hours were on our Mod I engines. Of course, the Mod II has just started to test.

That gives you a pretty good assessment of where we are in meeting the first goal, which was to develop an automotive Stirling engine. The second goal, which was to transfer that technology to the United States, really started with our initial relationship with

United Stirling of Sweden, who had the technology at the beginning of this program, back in 1978. That technology has assuredly been transferred to the USA team of NASA-Lewis and MTI. The Mod II was completely designed and procured here in the United States.

Through some of the comments that I will make now, you will see also that that technology transfer is now being passed on to a USA manufacturer and to some potential product users. The USA manufacturer involved is Deere and Company. During the past 12 months, I am pleased to report that they did participate in the development of the Mod II engine block, and cost shared to the effect of 25 percent in that effort. We are now in the process of establishing them as a subcontractor to manufacture, assemble, and test one of the Mod II engines in the program, so I think that John Deere does offer a very important base for the possible commercialization of this product.

This is a picture of the Mod II block as cast by John Deere that I made reference to.

The previous viewgraph that I showed really displays the fact that technology transfer is a process, and the end user is really the person who needs to be made aware of the virtures of the Stirling engine technology. We have two spinoff programs that have occurred in the last 12 months which give us a great deal of confidence that the commercialization process is taking shape.

The first one involved the U.S Air Force and NASA, and the application is for a maintenance van on the flight line. The participants in that program are Deere and Company, who will be cofunding their efforts, Purolator, and the American Trucking Association. The real interest on the part of the Air Force is the fact that the engine will use the JP-4 aircraft fuel that they use in the aircraft and it makes the logistics a little bit easier for them, and the projected lower maintenance costs associated with the Stirling engine. I should emphasis that that van program is funded by NASA technology utilization funds and does not come out of any DOE funding.

Another program which, again, is funded by the Army, is the use of a Stirling engine in a 25-kilowatt generator set. The attractive features of the engine here are, of course, its multifuel capability—they can use diesel or any kind of fuel they would get their hands on in a battle scenario—the quiet operation, and the difficulty in detecting a Stirling engine while it's running because of its low exhaust temperatures. The exhaust temperatures of a Stirling are about half that of a diesel.

Deere and Company offer the potential for a follow-on program with the Army where they would, in fact, manufacture the engine for that program.

So I think that we are starting to see commercialization reality here, and it's difficult for me to crystal ball exactly where it will end up but I would have to say that utility vans or generator sets are probably small markets to which the Stirling engine may be applied before the actual automobile application, which is a very difficult market to penetrate.

Let me just comment a little on what I feel are the results of the technology and the leadership that we have obtained through this program in Stirling engine technology. We have a professional engineering staff at MTI that is eager and ready to transfer the technology to industry. As you can see from the spinoff programs, we are starting to get some non-Government money support, and there are other nonautomotive applications that we are seeing this technology applied to.

The foreign competition is strong. We have done some intelligence of the activities, particularly in Japan, and we have identified a number of industrial, Government, and university participants. This is simply a list of the companies and the agencies who are all working on Stirling engine development in Japan. I myself and Mr. Goldwater plan to visit Japan in 4 weeks to see firsthand.

There are some rather interesting names up there. Aisin Seiki we know is a division of Toyota. They have put a Stirling engine on a Toyota car and run acceleration and mileage tests. Asahi Glass is a ceramic company, and they have built ceramic Stirling engines, so there are a number of activities going on in Japan that we know of.

This is also a graphic from a report obtained in Japan, and it confirms the subcommittee's original identification that the Stirling engine technology for a passenger car is indeed the most difficult, not only from a practical product development point of view but from a marketability point of view, and we have certainly found that out. That high level of technology that we have now obtained by virtue of your support in this program enables the application to be applied for air conditioning and power generation, as we know the Japanese are targeting their products for.

So, in summary, I would like to recommend to the subcommittee that the ASE development program be authorized for $8 million for fiscal year 1987 in order to complete the program on schedule, as we have promised, and that I think in order to keep this technology lead, that a technology development program similar to the types of technology programs we have had in the gas turbine and diesel areas over the past be initiated so that we can allow the process of commercialization to take form in the country while we maintain our leadership in this technology.

The concludes my summary of my testimony, Mr. Chairman, and I would be quite happy to answer any questions you may have.

[The prepared statement of Mr. Nightingale follows:]

HEARINGS ON DOE TRANSPORTATION PROGRAMS

Subcommittee on Transportation, Aviation, and Materials
Committee on Science and Technology
U.S. House of Representatives

Automotive Stirling Engine Development Program

Presented by:
Noel P. Nightingale
Director of Programs
Stirling Engine Systems Division

February 27, 1986

MECHANICAL TECHNOLOGY INC.

About the Author . . .

Noel P. Nightingale

Mr. Noel Nightingale is the Director of Programs at the Stirling Engine Systems Division of Mechanical Technology Incorporated, Latham, New York, a high-technology research, development, and manufacturing company. He has managed the ASE program almost since its inception in 1978 and has authored various papers on its progress. He has also been instrumental in transferring Stirling technology to industry and product users during the past few years. Prior to that, he was employed for more than 12 years with Pratt & Whitney Aircraft, a division of United Technologies Corporation. During that period, he undertook technical and managerial roles in the design, analysis, and development of military and commercial gas turbines and large (100 MW) ground power units. He also has management experience in multinational consortiums and aircraft maintenance. Mr. Nightingale holds a Bachelor Degree in Mechanical Engineering from the University of Toronto and Master Degrees in Engineering Science and Business Administration from Rensselaer Polytechnic Institute.

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TESTIMONY ON THE AUTOMOTIVE STIRLING ENGINE DEVELOPMENT PROGRAM
before
Subcommittee on Transportation, Aviation, and Materials
Committee on Science and Technology
U.S. House of Representatives

Mr. Chairman, members of the subcommittee, my name is Noel Nightingale, and I am the director of programs at the Stirling Engine Systems Division (SESD) of Mechanical Technology Incorporated (MTI). The Automotive Stirling Engine (ASE) Development Program is funded and managed by the Department of Energy (DOE). The NASA-Lewis Research Center located in Cleveland, Ohio, is responsible for the project management of the program. MTI is the prime contractor on the program. MTI is a high-technology research, development, and manufacturing company located primarily in the state of New York, with wholly owned subsidiaries in Michigan and California. The SESD engages approximately 120 people in the development of Stirling engines for a variety of applications. This team, primarily professionals, was formed by MTI in response to the national need for an advanced energy-efficient technology, in this case, the Stirling engine.

Mr. Chairman, MTI appreciates the opportunity to appear before this subcommittee to testify on the ASE development program. It is my pleasure to report that the ASE program continues to achieve its technical goals, while remaining on schedule and within budget. The program is on target for the development of a Mod II engine and the final demonstration of the overall program goals in FY87.

My testimony reports on the status of the ASE program in meeting its two goals which are to:

- Develop an automotive Stirling engine and
- Transfer Stirling engine technology to the United States.

In addition, I shall comment on the increased participation of industry and potential product users in the program. I will also comment on a proposed Stirling Engine Technology Program to follow the completion of the ASE Development Program to ensure that the United States maintain the lead in this important technology. Comments will also be made on Stirling engine developments in Japan. Finally, I will close with a set of conclusions and recommendations. All figures referenced in the text are included, for your convenience, in numerical order at the end of this testimony.

BACKGROUND

In Section 302(b) of Public Law 95-238, the United States Congress charged the DOE with initiating programs leading to the development of advanced automotive propulsion systems. DOE selected two basic engine cycles: the gas turbine and the Stirling. The Stirling engine was selected because of its intrinsic capability to provide high cycle efficiency; i.e., when installed in an automobile, the Stirling engine can attain a higher fuel economy than that of conventional power systems. Further, since the engine uses a continuously burning external combustion system, it is capable of using a variety of liquid fuels while maintaining low emission and noise levels.

The logic set forth in the program was to develop two experimental engines in sequence. The first engine, the Mod I, was a new engine design based on Stirling engine technology as it existed at the beginning of the program in 1978. The second engine, the Mod II, was to incorporate technology advancements made during the course of the ASE program and was to demonstrate the program objectives. The program is currently entering its final phase; the Mod II design has been completed and the first engine is being tested.

The ASE program has a number of specific objectives stemming from the public law. They are:

- A 30% improvement in fuel economy over a comparable production spark-ignition engine
- Operation within strict emissions standards ($NO_x \leq 0.4$, $HC \leq 0.41$, $CO \leq 3.4$ grams/mile, and particulates ≤ 0.2 grams/mile)
- Interchangeable operation on a variety of liquid fuels
- Reliability and life expectancy comparable to commercial engines
- Initial cost and life-cycle cost competitive with conventional engines
- Acceleration suitable for safety and consumer considerations
- Noise characteristics meeting Federal Standards.

SUMMARY

Although the time frame and magnitude of the ASE program have been altered by budget restrictions over the past years, progress toward the goals and objectives has not waivered. The 15 million dollars authorized by this committee last year and supported by the Congress enabled us to complete the design and procurement of the Mod II engine. MTI has done its utmost to meet the will of Congress by maintaining the schedule of the program and, as promised, MTI is requesting authorization of the 8 million dollars that was indicated last year as necessary to complete the program in FY87.

Significant progress has been made during the past year in transferring Stirling engine technology developed under the ASE program to industry and other potential users of the product. Deere and Company has participated as a cofunding subcontractor and in this the final phase of the ASE program is planning to manufacture, assemble, and test a Mod II engine. A program to assess the merits of a Stirling engine installed in an Air Force maintenance van has been initiated. Monetary support for this Van Program comes from NASA technology utilization funds, which are aimed at commercialization, and from Deere and Company, who will actively participate in the program and cofund their expenses.

Purolator and the American Trucking Association are also participants in the Van Program. Purolator is evaluating the lower maintenance costs of the Stirling, since the company uses a fleet of vans for its business. Both Purolator and the American Trucking Association are interested in the higher fuel economy of the engine. In another separate program, the Army is studying the use of the Stirling engine in a 25-kW generator set. A unit is currently undergoing tests at an Army site. The ASE program plays a critical role in supporting these demonstration programs by loaning out Mod I engines that are no longer in use in the ASE program.

Programs involving product users and engine manufacturers are critical to the ultimate commercialization of Stirling engines. Such programs are also crucial to ensuring that the United States keep its technology edge over foreign competition which has given high priority to the continued development of Stirling engine technology. To protect our current status and to allow the maturity of Stirling technology to take place, it is recommended that a Stirling Technology Program be initiated and authorized for 4 million dollars in FY87, simultaneous with the closure of the ASE Development Program. This recommendation is in keeping with past practices of Government to support the continuation of gas turbine and diesel engine technology until commercialization had taken place in the industrial sector.

BENEFITS OF THE ASE PROGRAM

To achieve national acceptance, a Stirling engine developed for the automotive application must be capable of meeting a number of stringent requirements. It must be small enough to fit within the structure of current vehicles, which are becoming more and more streamlined each year. It must provide sufficient power to meet the demanding performance requirement of today's cars. It must be efficient over a wide range of power and speed by providing high fuel economy both in the stop-and-go environment of city driving and the constant-speed cruising of highway driving. But most importantly, it must be inexpensive to manufacture in order to provide manufacturers an economical advantage to penetrate existing markets, as well as an incentive to develop new market sources. It must be inexpensive to operate in order to provide users an economical reason for choosing a new technology that does not dislocate their spending habits. Until the creation of the Mod II, Stirling engines were unable to meet these requirements; but through the technology developed under the ASE program, they can be met. Industry and users are only now becoming aware of this fact.

The wisdom of Congress in deciding to develop the Stirling engine for the automotive application, as opposed to other applications, continues to be confirmed. A high level of technology is required to develop an automotive Stirling engine and the goals are difficult to achieve. Once the goals are achieved, however, there are almost immediate windfall benefits to other applications. Examples include light-duty and heavy-duty vehicles, generator sets, irrigation pumps, solar electric units, heat pumps, industrial prime movers, submarines and other marine applications, and farm equipment. Whereas the free fallout of ASE technology to other applications may be a somewhat subjective assessment, it serves to underscore a key national benefit - that the ASE program provides the United States with a core technology having a host of spin-off applications. These, in turn, can provide our nation with a greater capability for conserving energy, as well as maintaining the technological leadership in those areas.

The payoff of introducing Stirling technology into the United States is a vast potential for new jobs related to new products, their manufacture and service, as well as an increase in associated trade employment. The multifuel capability of the Stirling engine will provide personal and national security in times of petroleum dislocation. The Stirling engine will meet the emission standards defined in the Clean Air Act, thereby contributing to the national effort to upgrade our environment. The ASE also provides an advantage to improving our noise environment, since the noise level emitted from a Stirling engine is much lower than that of conventional engines...a Stirling engine requires neither a catalytic converter nor a muffler. Finally, the overall potential for conserving valuable fuel resources through the use of more efficient Stirling engines in automobiles and in other applications is immense.

1985 ACCOMPLISHMENTS

During 1985, significant progress was made toward the program goals. The Mod II design was completed and engine hardware procured. The first Mod II was tested, as scheduled, in January 1986. Critical technologies were further developed during the year, resulting in improvements in vehicle fuel economy and performance while demonstrating increased life and reliability. An engine manufacturer, Deere and Company, became actively involved in the program and cofunded expenses. And finally, two demonstration programs were initiated through the loan of Mod I Stirling engines from the ASE program. In one of these programs a 25-kW generator set was assembled and is being tested at an Army site. In the other, a maintenance van will be prepared for test at an Air Force base. Both of these programs are funded through separate sources. These activities are more fully described under "Spin-Off Programs."

Mod II Engine

The Mod II engine was designed to meet the program goal of providing a highly efficient automotive power plant with a competitive manufacturing cost. During the past year, the detailed design of the Mod II engine was completed. Figure 1 is a photograph of the Mod II engine showing its compact size. The Mod II was designed for installation in a GM Celebrity sedan. A picture of the Mod II installed in the engine compartment of a Celebrity is shown in Figure 2. As equipped by GM, the Celebrity obtains 26 miles per gallon in urban driving and 40 miles per gallon in highway driving conditions, yielding a combined mileage of 31 miles per gallon. With the Mod II engine installed, the Celebrity is projected to obtain 33 miles per gallon in urban driving and 58 miles per gallon in highway driving, yielding a combined mileage of 41 miles per gallon. This is 32% above that of the spark-ignition engine. All mileage quoted is for unleaded gasoline.

These projections are based on experience to date with the Mod I and Upgraded Mod I Stirling engines, which provides confidence for the Mod II. For example, Figure 3 compares the actual combined vehicle mileage achieved with the Mod I and Upgraded Mod I Stirling engines and the combined mileage expected for the Mod II. The figure shows that the Upgraded Mod I achieved a 22% fuel economy improvement above that of the spark-ignition engine installed in the same vehicle. The projection for a 32% improvement with the Mod II over the spark-ignition engine is therefore very reasonable.

Comparisons of fuel economy should not be made, however, without a simultaneous comparison of vehicle performance. The major criterion used to measure vehicle performance is the time required for a car to accelerate from stop to 60 miles per hour. This response provides a measure of the power generated by the engine in relationship to the weight of the vehicle. The generally accepted automotive industry standard is to accelerate to 60 miles per hour in 15 seconds, although there is considerable variation among models. Until recently, vehicle performance impeded the Stirling engine from competing with spark-ignition engines. The Stirling engine was excessively heavy and exhibited poor transient characteristics, as compared to its maximum power level.

The Stirling engines used early in the program delivered an acceleration time of 36 seconds. The Mod I installed in an AMC Concord accelerated in 28 seconds, and an early upgraded Mod I engine installed in an AMC Spirit accelerated in 26 seconds. It was not until specific Mod II technologies were incorporated into the Upgraded Mod I engine that the acceleration time was reduced to 16 seconds. This level of performance provides confidence in the predicted acceleration for the Mod II of 12.5 seconds, as compared to the spark-ignition engine (Celebrity) acceleration of 13 seconds. Figure 4 depicts graphically the improved acceleration time achieved in Stirling engines over the course of the program.

Only three Mod II engines will be manufactured under the ASE Development Program, given current funding levels. During the past year, Mod II engine hardware was procured for the two engines scheduled to be built by MTI. Deere and Company will procure and build the third Mod II engine. The first engine assembly began in late 1985 and it was tested for the first time in January 1986. The schedule shown in Figure 5 was also presented during testimony to this subcommittee a year ago. It is shown again to emphasize the fact that the Mod II schedule has been maintained and to show that the remainder of the program will be devoted to testing and developing the Mod II engine. A Celebrity will be prepared and equipped with a Mod II engine to demonstrate the program objectives by the end of FY87. The requested FY87 authorization of 8 million dollars will be used to support this work. Two photographs of the first Mod II engine are presented as Figures 6 and 7. Figure 6 portrays the engine partially assembled with the four pistons protruding above the engine block. Figure 7 is a photograph of the fully assembled engine mounted in MTI's test cell.

Stirling Engine Reliability

During the past year, Mod I engines continued to develop useful life and reliability data while undergoing extensive testing. Figure 8 shows that during the past year, 5716 test hours were obtained on Mod I engines bringing the total accumulated level to 14,397 hours. Such testing has yielded valuable information on the life and reliability of seals, materials, and combustors. In addition, it has yielded data on the formation of emissions and soot during transient operations such as engine start-up and vehicle acceleration. If industry and consumers are expected to accept the Stirling engine, they must be convinced of its reliability through thousands of test hours. Warranty claims and maintenance costs are prohibitively high when products are found to be unreliable. This fact alone constitutes sufficient reason for continued, active testing of the Mod I engines in the program.

Engine Manufacturer

The second goal of the ASE program is to transfer Stirling engine technology to the United States. It has been MTI's intention that to involve an engine manufacturer in the activities of the program would be the most expedient means of accomplishing this goal. During the course of the program, we have gained notice and respect from industry. Their reaction has changed from negative to positive, yet without commitment. It is with great pride, Mr. Chairman, that I am able to report to you that Deere and Company has participated in the ASE program during the past year, cofunding their expenses at a rate of 25%, and that they will perform as a subcontractor to manufacture, assemble and test one Mod II engine during the remainder of the program.

One of the major parts designed into the Mod II that contributes to its lower cost and compact size is its single-piece engine block. Compared to engine blocks used for spark-ignition engines, a Stirling engine block is more complex because it houses many internal passages that must be absolutely leak proof. Manufacturing the Mod II block required extensive casting development, which Deere and Company willingly did at their own expense. Figure 9 is a picture of the Mod II engine block casting developed by them. The view shows the cylinder cavities that house the engine pistons.

It is felt that the active involvement of Deere and Company is the single most important reason to substantiate our requested authorization for FY87 to complete the ASE Development Program. Their involvement provides the mechanism to pursue commercialization of the engine and ultimate return to the Government of the money invested in the ASE program.

Spin-Off Programs

Two programs have been initiated that utilize Mod I engines borrowed from the ASE program. One program centers around the use of a maintenance van by the Air Force on aircraft flight lines. Such vans are used to transport men and materials from service hangars to aircraft parked on the lines. Vans experience considerable stop and start operation and rarely are required to travel above 30 miles per hour. Current vans are powered by diesel engines. The Stirling is an attractive power plant for this application in that it can accept the same fuel (JP-4) as used in the aircraft. The program spans three years and is supported by NASA technology utilization funds, since it is intended to lead to commercialization. Participants include the current NASA/Lewis and MTI team, as well as Deere and Company, Purolator, and the American Trucking Association. Deere and Company is funding a portion of the program.

The second program is centered around the demonstration of a Mod I Stirling engine in a military 25-kW generator set. The active participants in this program are NASA/Lewis, MTI, and the Army. A Mod I engine borrowed from the ASE program was installed in an Army generator set normally powered by a diesel engine. The unit is currently going through performance tests conducted by the Army. It will be followed by 500 hours of endurance testing. The Stirling engine is appealing for this application because of its multifuel capability and quiet operation. Another attractive aspect is its low-temperature exhaust which makes a Stirling engine unit more difficult to detect. It is anticipated that after the initial demonstration, a field test program involving many Stirling-powered generator sets will be put in place. It is expected that Deere and Company would manufacture the engine units for the program, making use of the knowledge gained from manufacturing a Mod II engine in the ASE program.

Stirling Technology Program

The United States possesses a distinct lead in Stirling engine technology over the remainder of the world by virtue of the achievements made in the ASE program. This lead should continue to be secure if we, as a nation, continue to develop Stirling engine technology. Also, the breadth of the engine's application is already apparent, as evidenced through the interest shown by Deere and Company and the spin-off programs discussed above. It is the technological lead already attained and concern for the future economic security of this nation that prompts MTI to recommend and request an authorization of 4 million dollars for a follow-on Stirling Engine Technology Program in FY87.

MTI is very proud of the accomplishments made within the ASE program. The technology of the Stirling engine has clearly been advanced to the point where it is no longer a laboratory curiosity but rather a viable alternative power plant ready to enter prototype and preproduction development. Even though the manufacturing cost, specific weight, and specific volume have been reduced to levels competitive with spark-ignition and diesel engines, there are weaknesses where the technology requires further development. Certainly the use of cost-effective ceramics in the design of the engine is required. Although ceramic technology development has been part of the ASE program, the use of ceramics has not been fully explored because of lead time and funding restrictions. Also, the combustion control system has not been sufficiently developed to allow its use with alternative fuels.

Emphasis was placed on the use of unleaded gasoline for the automotive Mod II demonstration. Whereas the use of alternative fuels has been demonstrated, knowledge of the specifics of properly controlling the operation of the engine is incomplete. Likewise, the long-term corrosive and errosive effects on combustion system materials are not known. Lastly, the engine has demonstrated adequate life and reliability at normal ambient temperatures but has not been fully developed to operate satisfactorily at temperatures in the vicinity of -20°F.

Quite logically, one may ask why these shortcomings exist. These technological difficulties take more time to overcome than the ASE program has been able to afford. The emphasis has been on demonstrating fuel economy and emission objectives. When comparing the money spent to date on Stirling engine development to the billions of dollars invested in the development of other engine systems, it is not surprising that some technical weaknesses still exist.

Mr. Chairman, this committee and, indeed, all of Congress should be complimented for their foresight in authorizing and supporting the continuation of the ASE program over the past years. The nation has benefited from your direction as it has available a new technology which allows flexibility in our consumption of various energy forms. And, it is a technology for which the United States possesses a distinct lead over every other nation. However, the effort should not be stopped, since other nations, particularly Japan, are quickly accelerating their efforts in this field. Within the United States, one engine manufacturer and a few other product users are just becoming actively involved in assessing and utilizing Stirling technology. By virtue of the ASE Development Program, a critical organization is in place at MTI capable of transferring Stirling technology to them, which is a primary program goal.

Therefore, Mr. Chairman, it is hoped that the same foresight that obliged this committee to initiate and support the ASE program will cause it to continue to keep the United States in the lead on Stirling technology. Authorization to continue development of the Stirling engine via the recommended Stirling Technology Program beginning in FY87 will accomplish this goal. Such an approach is not without precedent. In the past, the Government has been supportive of both gas turbine and diesel engine technology programs in order to keep the United States at the forefront of those technologies.

Stirling Engine Development in Japan

Nearly 70% of the primary energy requirements in Japan rely on imported petroleum. Although the supply and demand for oil is currently stable, the long-range scenario for a stable supply is doubtful. The development of new nonpetroleum engines and the technical development of energy-conserving equipment has been recognized as necessary. A large-scale Japanese research and development project entitled "Stirling Engines for Wide Use" was set up and started in 1982. This was part of an energy conservation program named "Moon Light Project" at Japan's Agency of Industrial Science and Technology (AIST), Ministry of International and Trade Industry (MITI). Total funding is nearly 10 billion yen (50 million U.S. dollars) for the six-year Stirling engine development effort authorized through FY87.

The Stirling engine project objective is to realize 3-kW and 30-kW class engines with high efficiency, low emissions and multifuel capability. Engine test demonstrations are to be made in FY87 for use in heat pump power plants to heat and air condition both residential and commercial buildings. In addition, engine test demonstrations will be made on industrial and construction machinery. This includes electric power generation. Four industrial companies participate in the program: Mitsubishi Electric Corporation, Toshiba Electric Corporation, Aisin Seiki Company and Tokyo Sanyo Electric Company. From a review of available literature, it is our opinion that all efforts have been directed toward the development of the Stirling engine with little or no system development. If this assessment is correct, it is our opinion that the United States has at least a three-year lead on the technology.

In addition, MTI has been able to ascertain the status of other Japanese nongovernment-sponsored Stirling engine development. The front runners in a listing of some sixteen industrial firms named as investigating various applications of the Stirling engine appear to be the following. Aisin Seiki formed a separate group to install a Stirling engine in a Toyota for demonstration purposes. The Asahi Glass Company has developed ceramics for Stirling engines and is currently developing a second-generation engine. The Sanden Corporation is developing a 2.5-kW Stirling engine for application in a residential heat pump that they plan to commercialize in 1987.

Japanese university and government agency activities include as a minimum: Tokyo Institute of Technology, Ceramic Material Development and Analysis; University of Tokyo, combustion and analysis; Meiji University, application studies and heat transfer; Agency of Science and Technology, analysis; and the National Aerospace Laboratory, combustion.

Conclusions

Based upon the points raised in this testimony, Mr. Chairman, I would like to summarize with the following conclusions:

1. The Mod II Stirling engine will meet the goal of Title III of Public Law 95-238 to develop an alternative automotive power plant.

2. The ASE program has accomplished the second goal of the program by transferring Stirling engine technology to the United States - the Mod II was designed and manufactured in America.

3. MTI has carried out the will of Congress by continuing to conduct the ASE program on schedule, while meeting the technical milestones and objectives requested and funded.

4. The foresight of Congress and, in particular, this committee in supporting the continuaton of the ASE Development Program in the past years was borne out this year when a major engine manufacturer entered the program, and two major spin-off programs emerged involving product users.

5. Technology transfer, the process whereby product users become aware of a technology, is beginning to occur for the Stirling engine.

    a. To discontinue the development of Stirling engines would stop this process.

    b. Through demonstration programs, the advantages of Stirling technology will be proven, and the product user will then create a demand for the technology.

6. Associated with the success of the ASE Development Program, and already in place is a dedicated team of professionals prepared to translate their knowledge to American industry and to product users. Without the continuation of the ASE program and the support of the U.S. Government, the solidarity of this team will be compromised.

7. Through the foresight of Congress, the United States has attained a worldwide leadership in Stirling engine technology for a broad range of applications in addition to the automotive field. The attention and support given by foreign governments and industries to Stirling engine technology threaten this leadership.

8. The first market in which the Stirling engine will be commercialized may not be the automotive field because of the inherently high warranty risks. Rather, it is more likely to be commercialized in a special market segment where product development can continue without major impact. Two likely candidate markets are utility vans and generator sets. These commercialization efforts will be choked off unless Stirling technology continues to be developed.

Recommendations

With the foregoing conclusions in mind, Mr. Chairman, I would like to make two major recommendations. I recommend that the ASE Development Program be authorized to continue through FY87 to complete the demonstration of the program objectives and to allow further progress in transferring Stirling technology to American industry and product users.

Secondly, I recommend that a Stirling Engine Technology Program be initiated in FY87 to allow for the continued advancement in Stirling engine technology to occur as precedented by Government's role in the past in maintaining American leadership in gas turbine and diesel technology.

Thank you, Mr. Chairman, for the opportunity to appear before this important committee, and may I offer to answer any questions at this time.

Figure 1 Mod II Stirling Engine - 80 hp

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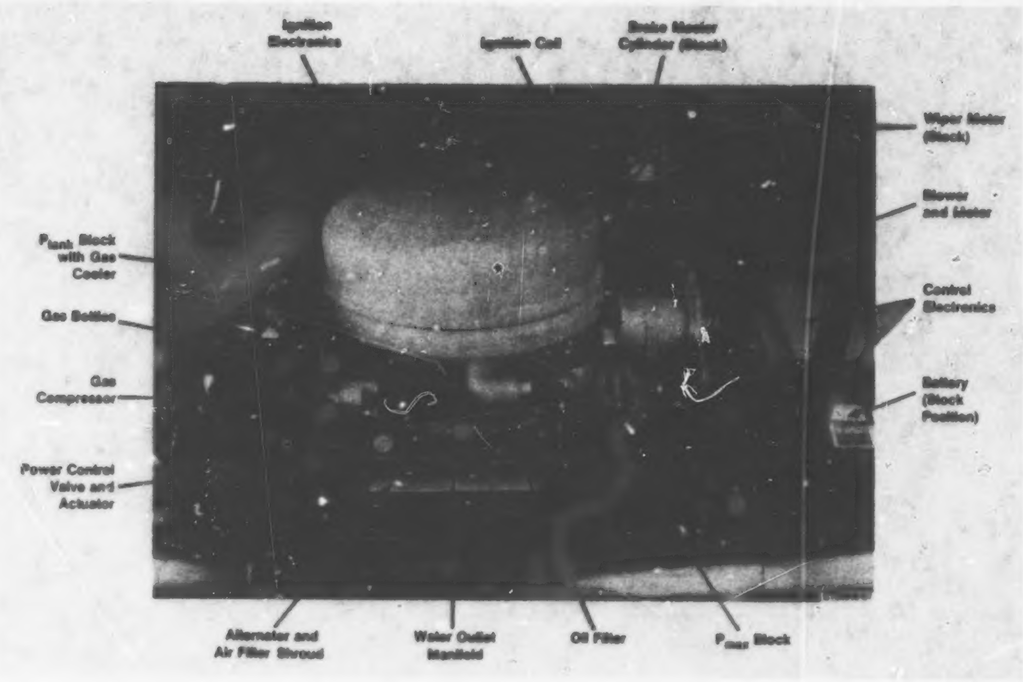
Ignition Electronics
Ignition Coil
Brake Master Cylinder (Stock)
Wiper Motor (Stock)
Blower and Motor
P_{tank} Block with Gas Cooler
Control Electronics
Gas Bottles
Gas Compressor
Battery (Stock Position)
Power Control Valve and Actuator
Alternator and Air Filter Shroud
Water Outlet Manifold
Oil Filter
P_{max} Block

Figure 2 Mod II Celebrity Installation; Upper Front View

81

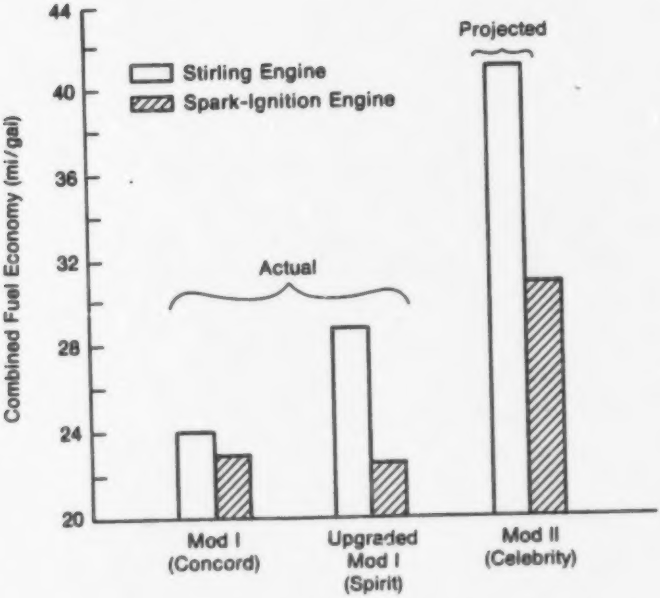

Figure 3 Stirling Engine Combined Mileage Compared to Spark-Ignition Engine

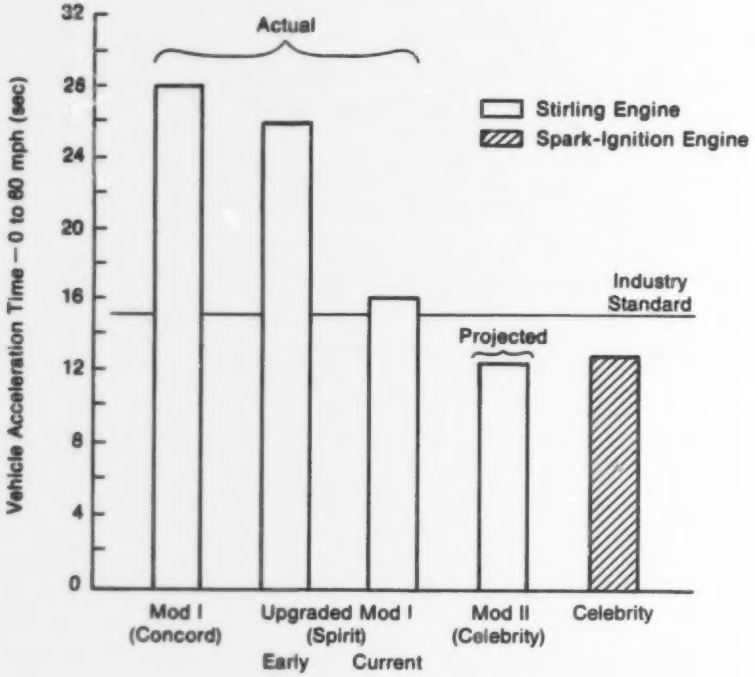

Figure 4 Stirling Engine Acceleration Compared to Spark-Ignition Engine

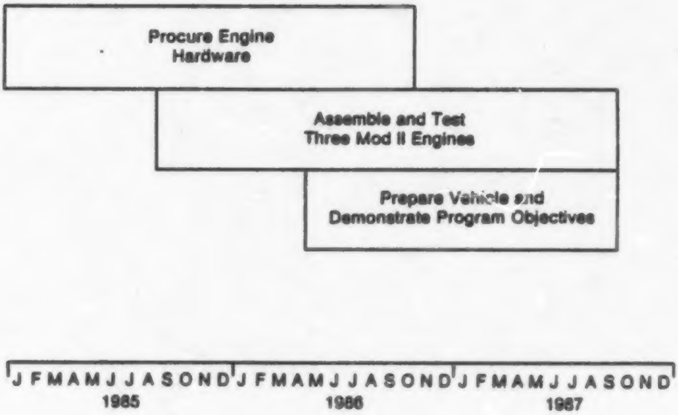

Figure 5 ASE Program Schedule: Mod II Engine Development

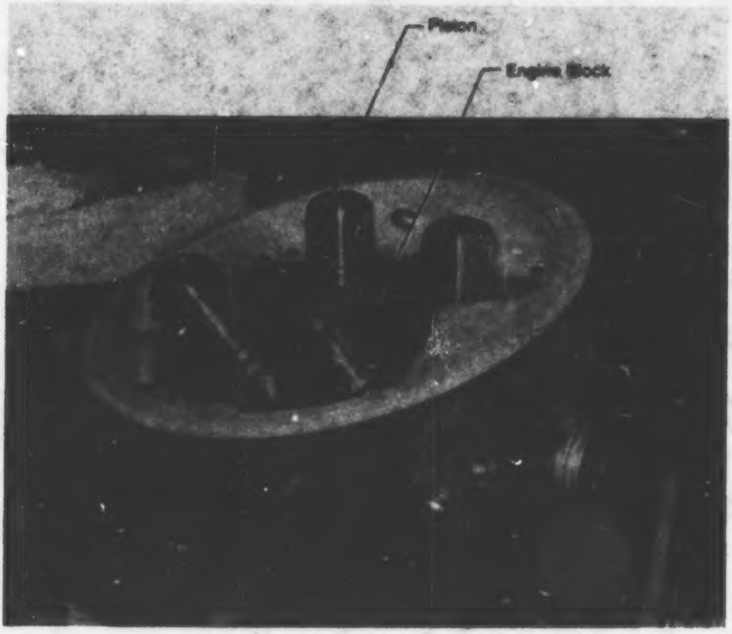
Piston
Engine Block

Figure 6 Partially Assembled Mod II Stirling Engine

Figure 7 Mod II Engine Installed in Test Cell

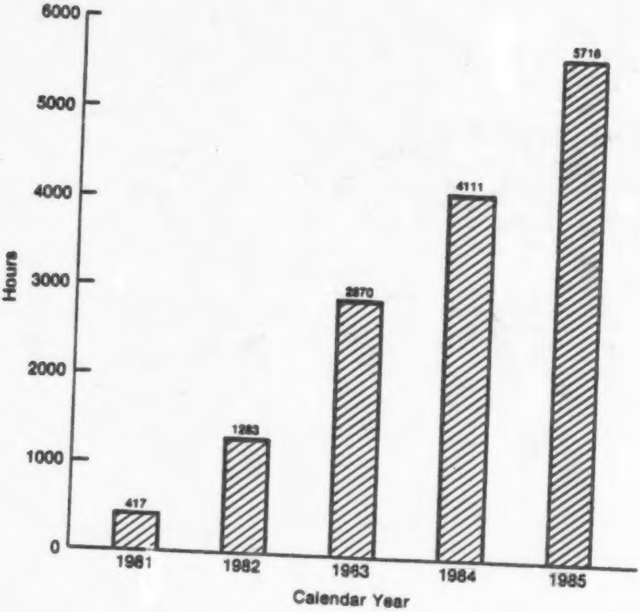

Figure 8 Mod I Stirling Engine Test Hours

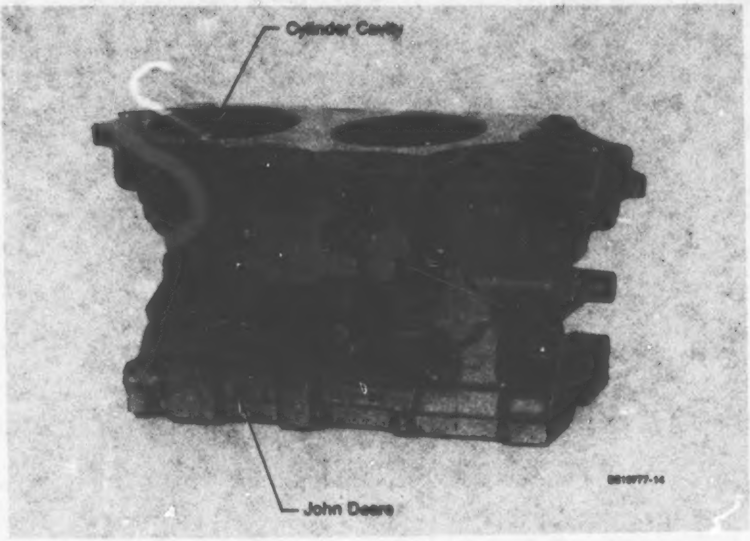
Cylinder Cavity
John Deere

Figure 9. Mod II Engine Block Casting

OUTLINE

- ASE Development Program
- Spin-Off Programs
- Stirling Engine Development Activities in Japan
- Stirling Engine Technology Program

ASE Development Program

GOALS

- Develop an Automotive Stirling Engine
- Transfer Stirling Engine Technology to the United States

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(Transportation Programs)

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HEARINGS

BEFORE THE

SUBCOMMITTEE ON TRANSPORTATION,
AVIATION AND MATERIALS

OF THE

COMMITTEE ON
SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

NINETY-NINTH CONGRESS

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FISCAL YEAR 1987 DEPARTMENT OF ENERGY AUTHORIZATION

(Transportation Programs)

TUESDAY, FEBRUARY 25, 1986

House of Representatives,
Committee on Science and Technology,
Subcommittee on Transportation,
Aviation, and Materials,
Washington, DC.

The subcommittee met, pursuant to notice, at 9 a.m., in room 2325, Rayburn House Office Building, Hon. George E. Brown, Jr. (chairman of the subcommittee) presiding.

Mr. **Brown**. The subcommittee will come to order.

Today, the Subcommittee on Transportation, Aviation, and Materials will begin 2 days of hearings on the Department of Energy's fiscal year 1987 budget request for transportation. These programs were largely mandated by two bills which originated in the Science and Technology Committee; the Automotive Transport Research and Development Act and the Electric Vehicle Research, Development, and Demonstration Act, so we are particularly interested in reviewing their progress.

Transportation uses more petroleum-derived fuel—over 60 percent—than all other energy consuming sectors in the United States combined, and accounts for nearly 30 percent of all energy consumed in this country. Thus, the Department of Energy's vehicle and engine research and development programs are focused directly at improving the energy efficiency of the sector which shows the most potential for providing substantial reductions in our dependence on foreign oil. Clearly, we must recognize the importance of these research and development programs as a key component of our long-term national security.

The budget request for fiscal year 1987 is $19.8 million, less than half of what was appropriated for fiscal year 1986. While many of the automotive programs are moving successfully toward achieving the goals set out in the enacting legislation, we still have a long way to go in establishing the key ceramic and advanced materials technology base upon which these engines rely. Likewise, advancements in battery and electric vehicle technology, while encouraging, still have not reached their full potential. While we all are aware of the current budget situation, it is the responsibility of Congress to review the priorities proposed by the budget request to determine if they are indeed in the best interests of the Nation.

I look forward to a very informative and productive hearing, and welcome the expert witnesses who have agreed to assist the subcommittee today.

Mr. Lewis has a statement also; do I understand? And we'll put it in the record at this point. Either of you gentlemen have any statements?

[The prepared opening statement of Mr. Lewis follows:]

OPENINING STATEMENT OF HON. TOM LEWIS

Thank you, Mr. Chairman, the 1987 budget process is just beginning, but already it looks as if we are in for a difficult year.

We've tried for too long to satisfy to many interests. This year, thanks to Gramm-Rudman, the day of reckoning has arrived.

The budget that we will be reviewing here this morning will be particularly difficult. The Administration has proposed terminating or significantly scaling back a number of DOE's transportation programs, and all of these programs have their advocates.

Our job would be made much easier if these were useless programs or if there were evidence of mismanagement. However, this is not the case.

Waste, fraud, and abuse are easier to talk about than to identify, and in spite of the current petroleum glut, the goals of DOE's energy conservation programs are still valid today.

This year it will be especially important for the Administration and Congress to work together to ensure, not only that the maximum benefits possible are realized from the limited resources available, but also that, in terminating programs in the interes of economy, the benefits of dollars already spent are not lost.

Industry has responsibility in this regard also. I think it's appropriate to ask them to assume a larger role in bringing these technologies to the market place.

Mr. Chairman, I join you in welcoming our witnesses this morning and I look forward to hearing their testimony.

Thank you.

Mr. **LUJAN**. None.

Mr. **BROWN**. All right.

We welcome you, Miss Fitzpatrick, and you may proceed with your statement.

STATEMENT OF DONNA FITZPATRICK, ASSISTANT SECRETARY FOR CONSERVATION AND RENEWABLE ENERGY, ACCOMPANIED BY AL STREB, DEPUTY ASSISTANT SECRETARY FOR CONSERVATION, AND DR. MEL CHIOGIOJI, DIRECTOR, OFFICE OF TRANSPORTATION SYSTEMS

Miss **FITZPATRICK**. Thank you, Mr. Chairman. I have a detailed statement I would like to submit for the record.

Mr. **BROWN**. Without objection, it will be included in full.

Miss **FITZPATRICK**. Thank you. And I will summarize it orally, if I may.

I'd like to introduce my colleagues here at the table. I'm accompanied on my right by Mr. Al Streb, who is the Deputy Assistant Secretary for Conservation, and on my left, Dr. Mel Chiogioji, who is the Director of the Office of Transportation Systems.

Mr. **BROWN**. We welcome both of these gentlemen also.

Miss **FITZPATRICK**. We appreciate the opportunity to appear before the subcommittee today and provide information on our fiscal year 1987 budget request concerning the Department's energy conservation research and development programs in transportation. The budget for this program supports the goals and strategies of our national energy policy as well as the administration and congressional goal of deficit reduction.

The administration's goal in energy policy continues to be that of fostering an adequate supply of energy at a reasonable cost. The strategies for obtaining this goal encompass the maximum practical reliance on free market place decisions.

The objectives of the Department's energy conservation research and development programs in transportation are: to contribute to improved energy efficiency and to enhance the diversity of available end-use technologies in transportation. These programs provide the technology base which is necessary to support private sector efforts to develop technologies which are either more efficient or serve as alternatives to those which are based exclusively on petroleum.

In allocating our resources, we are concentrating on applying Federal funds where they can be most effective by sponsoring longer term, higher risk research and development for which the potential payoff is high but which private industry is unlikely to pursue alone.

The fiscal year 1987 budget request [illegible] vehicle propulsion R&D provides $4 million to initiate a follow-on gas turbine component development project which will utilize the component development experience and the ceramic industry subcontractor relationships which have been established by the present automotive gas turbine contractor teams and the existing test rigs and experimental engines.

The objectives of the follow-on project are: To continue the development of ceramic components for gas turbine applications in parallel with the Advanced Materials Development Program; and to establish the reliability of component designs and materials, expand the experimental data base in the operating environment, and develop the analytical tools required for ceramic component design.

In the automotive Stirling engine project, preliminary testing of a prototype Mod II engine on a dynamometer is scheduled to be completed in April. At that time, all of the engine designs and the test data for both the Mod I and the Mod II engines, the results of industry evaluations, and the prototype engines themselves will be available for transfer to industry.

Since this transfer of the developed technology will essentially accomplish the Federal program goals under our proof of concept strategy, we are not requesting funds for Stirling engine R&D in fiscal year 1987.

A total of $2.5 million has been requested for continuation of the heavy duty adiabatic diesel project. Component evaluations of developed ceramic structures in a single-cylinder test cell will be continued, and the actual design, by industry, of a baseline multicylinder adiabatic diesel system will be carried out. Initial experimental emissions evaluations for uncooled diesel operations will be conducted, and the heat transfer models for adiabatic diesel operation will be continued.

We have requested $1.3 million for the Alternative Fuels Utilization Program to continue the data collection and analysis of the methanol-fueled vehicle fleet operations and to continue performance investigations on conventional and advanced single and multicylinder engines using synthetic fuels. Test synthetic fuels will continue to be made for project activities and the scientific community. $4.1 million has been requested for Electric and Hybrid Vehicle R&D where the primary focus continues to be on the development of battery technology for vehicle propulsion.

In fiscal year 1987, the development of full-size experimental cells and modules of the flow-through lead-acid technology will be completed and delivered for laboratory testing and evaluation. The development of the electric vehicle's sodium-sulfur technology will be continued, with emphasis on the unique performance requirements for an electric van application, including cell development, cell interconnect strategy, and thermal management.

A zinc-bromine eight-cell battery stack will be delivered for laboratory testing utilizing the most advanced materials and electrolyte formulations.

Efforts will continue in fiscal year 1987 on the dual-shaft alternating current propulsion system technology for commercial van application, with emphasis on the integration of the vehicle control systems and the nickel-iron battery, including the single-point watering and the thermal management systems.

The design phase only of the second generation ETX-II single-shaft alternating current propulsion system will be completed in fiscal year 1987, and the hardware fabrication of components will be terminated. We are, therefore, not requesting additional funds for the ETX-II project in fiscal year 1987.

Fleet operational testing of new electric vehicle technologies will be phased out after completion of the testing and evaluation of current product improvements. Funding is requested to complete the laboratory and in-vehicle dynamometer testing at the Idaho National Engineering Laboratory.

The fiscal year 1987 request provides $6.5 million for the Advanced Materials Development Program. Program activities will include projects on materials and processing of monolithic silicon nitride and silicon carbide, oxide matrix and dispersion toughened composites, thermal and wear zirconia-based coatings, dynamic interfaces, data base/life prediction, and International Energy Agency standardization of ceramic materials and testing. The excellent coordination procedures established with both Government and industry laboratories will be maintained, and the National Materials Advisory Board Committee, established to review program planning and implementation, will be continued.

During fiscal year 1987, the High Temperature Materials Laboratory will initiate operations and begin placement of permanent User Staff personnel. Based on the fundamental and cross-cutting nature of the operations to be conducted at the laboratory, funding for the operational research staff will be provided from the Office of Basic Energy Sciences in the Department's Office of Energy Research. Therefore, no additional funds have been requested for this project within our budget.

Finally, we are requesting $1.4 million for 22 full-time equivalent positions to provide direction and management to the transportation programs.

In summary, the activities of the Department's transportation program cover a spectrum of projects structured to increase energy efficiency and reduce petroleum dependence in the transportation sector. Although the program is focused on the transportation sector, the technologies under development for high-temperature materials, advanced propulsion systems, batteries, and alternative fuels utilization have a wide range of applications in addition to transportation.

That concludes my statement, Mr. Chairman. I thank you for the opportunity to appear here today.

[The prepared statement of Miss Fitzpatrick follows:]

STATEMENT OF

DONNA R. FITZPATRICK

ASSISTANT SECRETARY

CONSERVATION AND RENEWABLE ENERGY

BEFORE THE

COMMITTEE ON SCIENCE AND TECHNOLOGY

TRANSPORTATION, AVIATION AND MATERIALS SUBCOMMITTEE

U.S. HOUSE OF REPRESENTATIVES

FEBRUARY 25, 1986

Mr. Chairman and Members of the Subcommittee, I appreciate the opportunity to appear before you today and provide information on the FY 1987 budget request concerning the Department's energy conservation research and development programs in the transportation area. The budget fully supports the goals and strategies of the Fifth National Energy Policy Plan. I will summarize those parts of the Plan which are relevant to the subject of today's hearing and discuss highlights of the FY 1987 budget.

NATIONAL ENERGY POLICIES AND STRATEGIES

Our national energy policy goal and strategies are intended to lead us along a pathway to growing energy stability, security, and strength. The Administration's goal in energy policy continues to be that Americans should have an adequate supply of energy, maintained at a reasonable cost. The strategies for attaining this goal encompass the maximum practical reliance on the free decisions of the people.

The strategies for achieving this energy policy goal are:

- o to minimize Federal control and involvement in energy markets while maintaining public health and safety and environmental quality; and
- o to promote a balanced and mixed energy resource system.

The FY 1987 budget implements these strategies by supporting development of a mix of technologies that can contribute to both energy supply and improved end-use efficiency. In allocating our resources, we are concentrating on applying Federal funds only where they are most effective by sponsoring longer-term, high-risk research and development for which the potential payoff is high but which private industry is hesitant to pursue. CE programs will be exploring cooperative research and development approaches with industry that would seek DOE partnership and support in technologies associated with vehicle propulsion. Participation in industry-formed cooperative R&D ventures to support longer-term, applied technology development may be an effective method to leverage scarce Federal resources. The budget continues the Administration's policy of not funding commercialization activities which are the proper province of the private sector.

TRANSPORTATION RELATED GOALS AND OBJECTIVES

The objectives of the Department's energy conservation research and development programs in the transportation area are to contribute to improved energy efficiency and enhanced diversity of available end-use technologies. These programs provide the technology base necessary to support private sector efforts to develop technologies which are either more efficient or serve as alternatives to those based exclusively on petroleum.

The importance of our efforts in this area is underscored by the fact that the transportation sector accounted for 27 percent of total U.S. energy consumption in 1985 and, more importantly, 63 percent of U.S. petroleum consumption, up from 51 percent in 1973. During this period, the private sector has made substantial investments in more efficient transportation technology and major improvements have been made, as evidenced by the fact that the average fuel economy of 1985 model year automobiles was 90 percent better than that for 1973 model year automobiles. Nevertheless, further technological improvements are possible in energy efficiency and in fuel flexibility. Our program focuses on highway vehicles because three-fourths of petroleum use in transportation is by highway vehicles. The remaining one-fourth is attributable to other modes, including rail, air, and marine.

FY 1987 BUDGET

The FY 1987 budget in the transportation area requests $19.8 million for operating expenses. This funding is required to continue a program of research and development based on specific strategies generated in accordance with industry inputs. The strategies include efforts to: (a) establish proofs-of-concepts and develop advanced heat engine technologies which have at least a 30 percent improvement in fuel efficiency over comparable conventional engines, meet emission, safety, and noise standards, have alternative fuels capability, and have competitive life-cycle costs; (b) advance battery and propulsion system technology for competitive electric and hybrid vehicles for passenger car, van, or light truck applications; (c) establish a fundamental ceramic and advanced materials technology base for heat engines; and (d) develop a utilization-oriented technology base for use of nonpetroleum-based fuels made from oil shale, coal, and biomass in both contemporary and advanced propulsion systems.

I would now like to describe our progress, our planned activities during FY 1986, and our request for FY 1987 for each of the sub-programs in the areas under your jurisdiction.

VEHICLE PROPULSION R&D

To achieve the objectives specified in P.L. 95-238, the Automotive Propulsion Research and Development Act of 1978, research and development has been pursued to establish technology bases for three advanced engine concepts: the automotive gas turbine (AGT), the automotive Stirling engine, and the heavy duty adiabatic (uncooled, minimum friction) diesel engine. Common to all of these advanced engine concepts is the requirement to develop improved high-temperature materials and components.

The Automotive Gas Turbine (AGT) project has been implemented through cost-shared proof-of-concept engine development contracts with two industry teams. A single-shaft configuration (AGT 101) is being developed by Garrett Corporation/Ford Motor Company and a two-shaft concept (AGT 100) by Allison Gas Turbine Division/Pontiac Motor Division of General Motors.

Application of high-temperature structural ceramic components is a critical technology barrier in both concepts because of the high operating temperatures necessary to achieve efficiency goals. Both industry teams have successfully integrated prototype ceramic components into engine builds at increasing temperature and power levels. By the end of FY 1986, both teams are scheduled to demonstrate proof-of-concept of a fully ceramized gas turbine engine on a dynamometer with the capability for operations at the temperature ranges and rotating speeds required. Although such a demonstration will represent a major breakthrough in gas turbine technology and, even more significant, an industry-wide capability to fabricate ceramic components from a variety of materials in complex near-net-shapes, more development is needed before the design and fabrication of ceramic components reaches the reliability and long-life requirements of advanced propulsion systems. This situation was recognized several years ago when the Advanced

Materials Development (AMD) Program was initiated to conduct the basic ceramics research necessary to establish a sufficient technology base from which industry could produce reliable, cost-effective engine components. In order for this strategy to be completely successful, an iterative mechanism must be available where the research results from the AMD program are fabricated into real engine components, tested under actual operating engine environments, and evaluation results fed back into the AMD research agenda. To assure that this important mechanism continues after the completion of the automotive gas turbine program, we have requested $4 million in FY 1987 to initiate a follow-on program which will utilize the component development experience and ceramic industry subcontractor relationships established by the present AGT contractor teams, and the existing test rigs and experimental engines. The objectives of the follow-on program are to continue the development of ceramic components for gas turbine applications in parallel with the AMD program, and to establish the reliability of component designs and materials, expand the experimental data base in the operating environment, and develop the analytical tools required for ceramic component design.

The Automotive Stirling Engine (ASE) project has focused on the development of a proof-of-concept engine with an industry team lead by Mechanical Technology, Incorporated (MTI), combined with United Stirling AB & Company of Sweden. Under this program, transfer of Stirling engine technology to the United States has now been accomplished. Over 14,000 hours of performance testing has been completed on seven MOD I experimental engines fabricated under the program and predicted performance goals for the design have been confirmed. Testing of an Upgraded MOD I

(MOD IA) engine, which operates at a higher heater-head temperature and contains much less strategic metal has also been completed. The evaluations of the two MOD I engines loaned to industry in FY 1984 have now been completed and the final design of a second generation engine configuration, the MOD II engine, was completed in FY 1985.

During FY 1985 and continuing in FY 1986, additional efforts to transfer the Stirling technology developed to other Government agencies and industry are being carried out. A MOD I engine has been loaned to the U.S. Army for installation in a military generator set. Negotiations are in progress to loan a MOD I engine to the Air Force for a van installation. Announcements have also been made in the Commerce Business Daily on the availability of MOD I Stirling engines for loan to industry for non-automotive application evaluations. NASA has maintained a close coordination with the program for possible application of Stirling technology for power in the space station project.

Testing of a prototype MOD II engine on a dynamometer will be completed during the first six months of FY 1986. At that time, all of the engine designs and test data for both the MOD I and MOD II engines, the results of industry evaluations, and the prototype engines themselves will be available for transfer to industry. Based on this information and equipment, industry can perform the assessments necessary to determine whether further commercialization efforts should be carried out. Since this transfer of developed technology will essentially accomplish the Federal program goals under our "proof-of-concept" strategy, we are not requesting funds for Stirling engine R&D in FY 1987. Phase-out program costs will be covered under FY 1986 appropriated funds and any surplus funding will be deferred.

The Heavy Duty Transport Technology project has focused on establishing a technology data base for industry development of uncooled, minimum friction, low heat rejection diesel engines (commonly referred to as adiabatic diesel engines). Elimination of the cooling system, with attendant high operating temperatures and recovery of the increased exhaust heat energy, offers the potential for greatly improved operational fuel economy (30 to 40 percent better) compared with 1982 technology. The research strategy has been to concentrate on technology barriers identified by industry and to plan development activities in such a way as to support industry efforts to introduce individual components and concepts. During FY 1986, evaluations of developed ceramic components will be initiated in a single-cylinder test cell, and industry requirements for the design of a baseline multi-cylinder adiabatic diesel system finalized. Development of a heat transfer model for high temperature diesel engine operations will be continued and second stage component development requirements identified. In FY 1987, developed component evaluations will be continued in single-cylinder test cells and the actual design by industry of a baseline system will be carried out. Initial experimental emissions evaluations for uncooled diesel operations will be conducted, and the heat transfer models for adiabatic diesel operation will be completed. A total of $2.5 million has been requested in FY 1987 for continuation of the Heavy Duty Transport Technology Development project.

Technology Assessment and Transfer activities of the Vehicle Propulsion R&D subprogram will be continued in FY 1987 to provide an ongoing assessment of related private sector developments and other Government-sponsored programs to assure that maximum coordination with industry is maintained, both for dissemination of research results and gathering of inputs on technology needs. These activities will be integrated with related subprogram activities and no separate funding has been requested for FY 1987.

ALTERNATIVE FUELS UTILIZATION

The goal of the Alternative Fuels Utilization Program is to establish a utilization oriented data base for alternative fuels in both contemporary and advanced heat engines. The approach has been to conduct systematic research on the fundamentals of alternative fuel use in both spark ignition and diesel engines, concentrating on nearer-term fuels first (alcohols) and expanding the data base in subsequent stages to include synthetic fuels and advanced engines.

During FY 1986, basic fuel/engine performance/emissions investigations are being continued to identify and provide understanding of engine problems associated with the use of synthetic fuels, and the facility at Southwest Research Institute will continue to provide industry and the scientific community with standardized synthetic test fuels. The Federal fleet methanol-fueled vehicle demonstration will begin operations with at least four different production vehicle types in three fleet locations. In FY 1987, the data collection and analysis of the methanol-fueled vehicle fleet operations will be continued and performance investigations on conventional and advanced single- and multi-cylinder engines using synthetic fuels will also be continued. Test synthetic fuels will continue to be made for project activities and the scientific community. A total of $1.3 million has been requested in FY 1987 for this program.

ELECTRIC AND HYBRID VEHICLE R&D

The goal of P.L. 94-413, the Electric and Hybrid Vehicle Research, Development and Demonstration Act of 1976, is to develop the technology, in cooperation with industry, that will lead to the production and introduction of electric vehicles into the Nation's transportation fleet and the substitution of more abundant sources of energy for petroleum-based fuels. Significant progress is being made in the Department's program and by the private sector in developing the technology of batteries and propulsion systems in order to achieve that goal. After intensive characterization testing by the Idaho National Engineering Laboratory, six General Motors Griffon electric vans have been placed into operational fleet testing by Detroit Edison in the Department's cost-shared test and evaluation program. More than thirty of these electric vans are being placed in fleets throughout the country by the private sector in a program coordinated by the Electric Vehicle Development Corporation.

The primary focus of the electric and hybrid vehicle program continues to be on the development of battery technology for vehicle propulsion. In FY 1986, the development of an advanced lead-acid battery based on the forced flow of electrolyte through porous lead and lead dioxide electrodes is continuing. This technology offers a 51 percent improvement in active material utilization over current lead-acid battery technology, resulting in a major increase in the specific energy of lead-acid batteries. Laboratory tests of experimental cells have demonstrated the viability of the flow-through concept. In addition, the flow-through technology would significantly increase the cycle life of lead-acid batteries. In FY 1987, the development of full-size experimental cells and modules of the flow-through lead-acid technology will be completed and delivered for laboratory testing and evaluation. In FY 1986, a contract is being negotiated for the development of sodium-sulfur battery technology for the electric vehicle application, based on the core technology development funded by the Energy Storage and Distribution Division. For the electric propulsion application, the optimum cell configuration and interconnect strategy as well as the thermal management system are being investigated. In FY 1987, the development of the electric vehicle sodium-sulfur technology will be continued with emphasis on the unique performance requirements for an electric van application including cell development, cell interconnect strategy, and thermal management.

In FY 1986, the development of zinc-bromine battery technology for the electric vehicle application is being continued. Significant progress is being made on controlling electrode warpage to an acceptable minimum and increasing the reliability of the complete battery subsystem. Initial tests of experimental cells in compression are demonstrating improved performance and longer cycle life over current cell designs. In FY 1987, a zinc-bromine 8-cell battery stack will be delivered for laboratory testing utilizing the most advanced materials and electrolyte formulations.

In addition to battery technology development, the program is also developing an advanced electric vehicle propulsion system. In FY 1986, the second generation of the single-shaft a.c. propulsion system (ETX-II) was continued for an electric van application. The first generation powertrain was installed in a proof-of-concept passenger car and tested on a dynamometer and on a test track. A full-scale zinc-bromine experimental battery and a portion (1/3 scale) of an experimental sodium-sulfur battery have been successfully tested as part of the propulsion system. An experimental full-scale tubular-plate lead-acid battery has been delivered and is under test as part of the propulsion system evaluation. For the second generation system a full-scale permanent magnet (neodymium-iron) motor, together with breadboards of the associated power electronics and control systems, have been fabricated. In FY 1987, the design phase only of the second generation single-shaft a.c. propulsion system will be completed using unexpended prior year obligations and hardware fabrication of components will be terminated.

In FY 1986, research and development of a dual-shaft a. c. propulsion system is being continued for an electric van application. This effort includes the development and vehicle integration of nickel-iron battery technology. The powertrain incorporates a two-speed automatically shifted transaxle with regenerative braking. In FY 1987, the development of the propulsion system will be continued with emphasis on the integration of the vehicle control systems and the nickel-iron battery subsystem including the single-point watering system and the thermal management system.

In FY 1986, testing and evaluation activities of electric vehicle technology include operational fleet testing and laboratory and in-vehicle dynamometer testing. Characterization testing of the General Motors Griffon electric van and the Eaton a.c. propulsion system was completed with in-vehicle dynamometer testing at the Idaho National Engineering Laboratory. Phase III gel cell batteries developed in the program were installed in vehicles and are being fleet tested by GTE, the University of Hawaii, and Sandia National Laboratory. Preliminary field test results of the gel cell batteries are consistently showing a significant reduction in energy use per mile compared to the flooded lead-acid batteries that were replaced in the vehicles, elimination of the battery maintenance problem, and increased overall system reliability. Additional product improvements such as nickel-iron and tubular-plate lead-acid experimental batteries and watering systems have been installed in vehicles by the User Task Force and are being tested and evaluated in fleet operations. In FY 1987, the fleet operational testing will be phased out after completion of the testing and evaluation of the product improvements program. Funding is requested in FY 1987 to complete the laboratory and in-vehicle dynamometer testing at the Idaho National Engineering Laboratory.

The total funding request for the Electric and Hybrid Vehicle R&D program in FY 1987 is $4,140,000.

ADVANCED MATERIALS DEVELOPMENT

Improved materials technology is a key requirement in all transportation propulsion R&D activities. In high performance energy conversion systems, and in particular in advanced transportation engines, operation at high temperatures in corrosive environments is essential for obtaining substantially improved efficiencies. A critical need is the development of ceramic, ceramic composite, or ceramic coated components which can withstand these operational environments. Although the advanced engine projects are providing the required focus to prove the feasibility of ceramic components, they have also demonstrated that a parallel basic ceramics research effort is necessary to assure future development of reliable and reproducible ceramic parts. The goal of the Advanced Materials Development Program is to establish an industrial ceramic technology base capable of providing reliable and cost-effective components for high-temperature, efficient propulsion systems while eliminating requirements for scarce strategic materials.

In accordance with the basic ceramic technology areas identified in the program plan--developed through a comprehensive industry assessment--research activities in FY 1986 will include continuation of projects for improved silicon carbide and silicon nitride powders, ceramic composites, thermal and wear coatings, joining ceramic-to-metal and ceramic-to-ceramic, life prediction and characterization of ceramic properties. During FY 1987, the phased activities on existing contracts and research projects will be continued, and some new research projects will be initiated essentially in accordance with a high pay-off focus of the program plan technology areas. Program activities will include projects on materials and processing of monolithic silicon nitride and silicon carbide, oxide matrix and dispersion toughened composites, thermal and wear zirconia-based coatings, dynamic interfaces, data base/life prediction, and International Energy Agency standardization of ceramic materials and testing. The excellent coordination procedures established with both Government and industry laboratories will be maintained and the National Materials Advisory Board committee, established to review program planning and implementation, will be continued. We have requested $6.5 million for the Advanced Materials Development Program in FY 1987.

The High Temperature Materials Laboratory (HTML) at Oak Ridge National Laboratory was initiated in FY 1983 to support advanced high-temperature ceramic and alloy materials research in both Government and industry. The HTML will have a unique capability with a broad multidisciplinary professional staff serving as a common focal point for industrial/university/Government participation and having access to high-cost research equipment. During FY 1986, construction on the laboratory facility will be continued and procurement of major items of research equipment will be initiated. In early FY 1987, the construction will be completed and equipment installation implemented with unexpended prior year construction obligations. During FY 1987, the HTML will initiate operations and begin placement of permanent User Staff personnel. Based on the fundamental and cross-cutting nature of the operations to be conducted at the HTML, funding for the operational research staff will be included in the Basic Energy Sciences budget of the Office of Energy Research. Therefore no additional funds have been requested for this project.

PROGRAM DIRECTION

To provide the overall program direction of the transportation program including the development of the strategy, plans and resource requirements, and integrated program management, we are requesting $1,400,000 in FY 1987.

SUMMARY

In summary, the activities of the Department's transportation program cover a spectrum of projects structured to increase energy efficiency and reduce petroleum dependence in the transportation end-use sector. Although the program is focused on the transportation sector, the technologies under development for high-temperature materials, advanced propulsion systems, batteries, and alternative fuels utilization have a wide range of applications in addition to transportation.

That concludes my testimony, Mr. Chairman, and I thank you for the opportunity to appear before you today.

Mr. **Brown**. Thank you very much, Miss Fitzpatrick.

Mr. Lujan do you have any questions that you——

Mr. **Lujan**. Yes. I attended a briefing on the ceramic engine the other day that Garrett was having. They said that they would need about $50 million instead of the four which we proposed, and I came away wondering. One of the symptoms of that particular engine would be really not for vehicles but like arms for pumping of water and those kind of stationary things. Is it very difficult to transfer that technology from one to the other? The reason I ask that, I thought we had some diesel engines that we used to pump the water, and I'd rather think that the same kind could be used in a big truck or something like that. Am I mistaken? Couldn't these be interchangeable?

Miss **Fitzpatrick**. The Garrett engine is designed for an automobile. And we're working on another engine for heavy duty truck; that's the adiabatic diesel engine. There are many aspects of both programs which are interconnected, most especially, the use of high-temperature ceramics which will be required in both engines. Transferring an engine that's designed for an automobile to another use, such as pumping water, is certainly possible.

Mr. **Lujan**. How about vice versa? My understanding was that they felt pretty comfortable with using it for stationary purposes.

Miss **Fitzpatrick**. It's much easier to take an engine designed for an automobile and put it in a stationary, rather steady power supply use than it is to go the other way, because an automobile engine must not only be efficient and produce a sufficient amount of power but also must be able to deal with rapidly changing demands, quick startup and stopping. A stationary engine, for something like pumping water, doesn't have to do that. So an engine designed for an automobile is rather easily transferred to a stationary use, but vice versa can be very difficult.

Mr. **Lujan**. Would they need, then, additional money, if, as a matter of fact, the Garret seems to be that we can use it for stationary purposes? Is $4 million then enough to work into research the transcript of an automobile-type engine?

Miss **Fitzpatrick**. I think so.

Mr. **Lujan**. The real pay-off is coming and that's——

Miss **Fitzpatrick**. That's right. Well, the real payoff we're looking for, of course, in this program is an automobile engine with significantly increased efficiency and fuel diversity. That Garret engine doesn't need gasoline. It can run on diesel fuel. It can run on alcohol with very little adjustment.

The $4 million that we had proposed in our budget is to maintain one contractor team, either the Garrett team, or the Allison/GM team in testing component fabrication and design. We have completed two engine designs, the Garrett engine and the Allison/GM engine, and we are satisfied that those engines work and that they will meet their design specifications.

The problem now is how do you make the ceramic components for those engines, make them in a highly reliable way, and in an economical way. And that we don't know how to do yet. So it's the components that are the focus. And I certainly won't deny that if we put more money into it and have two contractor teams working we'll probably get the job done faster and with a higher likelihood of success. Our problem is that we've been asked to give a budget that will support the program goals and not go beyond what is needed to support the program goals.

Mr. **Lujan**. Basically, what you are saying is that both engines seem to work.

Miss **Fitzpatrick**. That's right.

Mr. **Lujan**. Have they run already? Is that what you mean?

Miss **Fitzpatrick**. They have been running. They haven't yet run, but they are scheduled to run this fiscal year, at their full design speeds and temperatures. The Garrett engine, I believe, is scheduled this month to be run at full design speed and temperature.

Mr. **Lujan**. And so the only problem is how to make those ceramic components that are reliable and long-life to them.

Miss **Fitzpatrick**. That's right. And to make them in a mass production mode. You see, we can make ceramic components if you almost hand make them, but how can you turn them out in the number that would be needed to go into commercial production? So we need really to work on reliability.

Mr. **Lujan**. Sorry, Mr. Chairman, for taking so much time. But when you say they'll be—the Garret engine, for example,—will be ready to run at full speed sometime through fiscal year 1986, that is for use in automobiles? Or for use in stationary——

Miss **Fitzpatrick**. It is an engine designed for use in automobiles. It will not be powering an automobile. It's being run on a test rig, but it is designed to run an automobile, and that is the purpose of that engine. And, as I say, it's much easier to use it in a stationary steady power situation.

Mr. **Lujan**. Is it a good idea for us to continue with it until it gets into automobile capability? Or that in private industry it can be done, maybe not easily, but——

Miss **Fitzpatrick**. We are continuing the work since the design work, we think, is completed. We have a successful engine; two successful engines. The next step is, as I say, the component fabrication step. So we are continuing that, and industry is very interested. They have increased their cost-sharing, and we hope to see them continue to increase their cost-sharing.

Mr. **Lujan**. I am sorry to ask a question again, but I'm not quite sure of the answer. So you have the two engines that are——

Miss **Fitzpatrick**. That's correct.

Mr. **Lujan** [continuing]. Designed to do what they were originally hoped they would do. That is, work in an automobile.

Miss **Fitzpatrick**. That's right.

Mr. **Lujan**. Thank you.

Mr. **Brown**. Mr. Packard.

Mr. **Packard**. Thank you, Mr. Chairman.

Miss Fitzpatrick would you review with me one more time—I'm sure your statement did it, but it was more in dialog—now I'd like, just specifically, now which projects are we discontinuing that are not completed? Which ones are we completing? I think I understood the Stirling engine is completing in a few months.

Miss **Fitzpatrick**. Yes.

Mr. **Packard**. Those two things particularly now.

Miss **Fitzpatrick**. We are completing the Stirling engine project, through the testing of the prototype, which we expect to have finished in April. We would not propose building more engines of the Mod II design or doing further testng on it. We have run the Mod I engines of the Stirling model about 14,000 hours—or will have run it that long by the close of this fiscal year. We have a great deal of test data and understanding of how that engine is performing which is available to the industry.

We have made the Mod I engine available to John Deere and General Motors for them to look at, and they did not indicate that they are willing to pick it up for further development. We have also made the Mod I engine available for stationary applications such as water pumping and electrical generation. The Army has asked to take one because they were very interested in using it on a mobile field generator set. We think that the Stirling engine is very well adapted to stationary applications.

Mr. **Packard**. More so than novelty?

Miss **Fitzpatrick**. Oh, yes. It does not handle power demand—changes in power demand—very well, and that is the difficult thing about an automobile engine.

Mr. **Packard**. And the projects that we are discontinuing, that we've not completed yet, are there any?

Miss **Fitzpatrick**. We have tried not to drop a project before coming to some rational point of conclusion. It's true that we won't be able to carry out all of our planned development as rapidly as we would like to. For example, with the ETX-II propulsion system, we are not proposing that we continue with the component development in that. We really think, actually, that industry is capable of carrying that on. We have a completed design—and also what that really needs—that complete system really needs its power source, the battery. And we are looking to the sodium-sulfur battery to supply power for that and that we are carrying on development of that battery. So there is a kind of synergism, waiting for one part of the system to catch up to the other.

We are continuing work on the adiabatic diesel engine. That is not being stopped. We are not really stopping any program except the Stirling engine program.

We're not proposing anything for a complete stopping except, excuse me, there are also a couple of the battery types that we are not proposing that we work on further. We will continue the zinc-bromine battery, as I said, the sodium-sulfur battery, and some of the advanced lead-acid battery designs. We would continue working with the nickel-iron battery as part of the dual-shaft electric propulsion system, a contract with Eaton, that we'll be continuing. The battery we think is about ready. It's simply a matter now of integrating it with the propulsion system. The iron-air battery has a number of problems with it. The nickel-cadmium battery is quite expensive and simply loses out on the economic's side, so we've moved that to a lower priority.

Mr. **Packard**. How do you articulate your R&D work with the commercialization of it once you've come to a point where it is economically feasible and has some commercial application? How do you articulate that into the private sector?

Miss Fitzpatrick. We try to start our R&D program, from its very inception, in cooperation with industry. We consult with industry when we plan research. We don't start out on a project unless industry has told us that there is a need for what that project is designed to deliver.

We assure that they are sincere in their expressions of need by entering into cost-share contracts with industry. So it's not just our money, it's private sector money, that's going into the development. This not only assures that we are doing something that somebody cares about on the commercial side but also that they already have, because they are participating in the contracts, they already have the information that is being developed by the research. They not only have the information, but their people are actually working on it, have hands-on experience, and are gaining the knowledge as fast as we are.

There is a continuum of phasing out the Federal funding and phasing in increased industry work. At some point, the contractors generally like to say, "We would rather proceed on our own because we are approaching now proprietary product development information." As long as the Federal Government is involved that information is public, and so there is a kind of natural transition.

There is always a certain tension where we think we've done enough, and they don't think we have. I think, as long as both sides are a little bit disgruntled, perhaps we've hit the happy medium. But, we do try very hard to integrate industry into our research from the planning stages all the way through each phase of the development.

Mr. Packard. The Stirling engine—has there been any interest from foreign countries or foreign governments on the Stirling engines?

Miss Fitzpatrick. The basic engine design is actually being used in this country under license from United Stirling of Sweden, so it's really originated there. We have had some interest from the Chinese government. I believe they are interested in water pump type applications. And I understand, also, that there is a consortium being started between a university and the main contractor, Mechanical Technology, Inc., for commercial development of the engine.

Mr. Packard. What promise has your research shown, thus far, on the ceramic work you've done thus far on engines?

Miss Fitzpatrick. We are very enthusiastic about the potential of ceramics in American industry. As I mentioned earlier, ceramics are absolutely necessary if we are to have successful high-temperature, very efficient transportation engines for both automobiles and trucks.

The key to the efficiency in these engines is that they operate at temperatures above 2,000 degrees Fahrenheit—say in the 2,400 to 2,500 degree range—and that they be able to recycle their waste heat back into the engine instead of cooling the engine through a radiator system. Metals are not sufficient to handle that. All the metals we have would melt at those temperatures, therefore, ceramics are absolutely essential.

We think that we are making great progress in the design of the material itself. What chemicals do you put into that material in order to make something that will withstand the temperatures and the stresses that are in the engine? And then how do you handle it? How do you fabricate the components?

We are learning a great deal more about testing and standardization of materials. We are sharing that information with industry, and in the last year or two we have had very substantial increase in industry interest in ceramics. We have had companies increasing the size of their own research programs and companies getting into the field that weren't in it before. So we've been very encouraged about the progress.

Mr. PACKARD. And how much longer do you think we will be involved in the ceramic research before it is taken over essentially by private sector?

Miss FITZPATRICK. That's very difficult to say because, I think, ceramics are one of those fields where the potential is almost—it's very hard to define—it's very large. And the more we learn really about the basic behavior of the materials—and I'm talking about how do the atoms themselves, I'm down on the atomic level—how do those atoms interrelate? How do the surfaces behave? It's going to be years before we get past the basic—where there will be valuable basic work—that will be appropriate, I think, for Federal involvement.

Ceramics really are a field that is drawing interest and funding from a number of areas, not just in the Department of Energy, but in other areas of Government. We do have a coordinating committee that meets regularly to make sure that the work being done in different places is not redundant and that people are learning from what is being accomplished in other places.

Mr. PACKARD. I would have to assume that our space program has a great deal of research being done on ceramics.

Miss FITZPATRICK. Absolutely.

Mr. PACKARD. Is there a transfer of technology there?

Miss FITZPATRICK. Yes, there is. NASA's part of the coordinating committee.

Mr. PACKARD. There's a glaring void in all that we are doing in this area and that is new starts. Have we simply dismissed the potential of new starts in our research in energy?

Miss FITZPATRICK. That is a void, Mr. Packard, and it's distressing.

Mr. PACKARD. It's primarily an economic issue.

Miss FITZPATRICK. It is a budgetary issue, yes.

Mr. PACKARD. That's all I have, Mr. Chairman. Thank you.

Mr. BROWN. Thank you, Mr. Packard.

I'm going to recognize Mr. Lewis at this time and also ask him to preside for a few minutes while I have to take a necessary absence, and I'll be back very shortly.

Mr. LEWIS. OK, Mr. Chairman.

Mr. BROWN. Can you carry on?

Mr. LEWIS. I'll do my best.

Miss Fitzpatrick, in your opinion, what would happen if the Stirling engine program was terminated this time?

Miss FITZPATRICK. We now have the Mod I engine. I believe we have built seven engines which will have run for a total of about 14,000 hours under test conditions at the end of—if the program were terminated as we propose—so we have a great deal of data on how that engine performs.

We have built and are testing the prototype Mod II engine. The prototype testing will be completed in April of this year. We would have that engine, plus all of its test data, available to industry. I think that that is enough information and hardware so that industry, if it's interested in developing this engine, would have the base that they need to proceed.

Our problem with the Stirling engine is, basically, the purpose for which we are being asked to develop it, and that is as an automotive engine.

We think it's an excellent engine for other purposes. It does not respond very well to demands for power acceleration. It does very well—it's a very efficient engine—if you use it in an application where it simply runs steadily, and it doesn't have to speed up or slow down, for example, pumping water as an electric generation.

I mentioned that the Army is very interested in using it on a field generator kit set. We are using it for residential heat pump. We have a program with the Gas Research Institute in which we are developing the Sterling engine on a heat pump. We are using it also on our solar program as the heat engine and electrical generator on a solar dish, and that looks as if it's very promising.

All of these are applications where the engine simply gets up to speed and runs and runs and runs. It's very efficient and very promising. We have not had any particular interest from the transportation industry in developing the Sterling engine for an automotive propulsion system.

Mr. LEWIS. Do you think there's any reason to look at research at low revolutions per minute or low speeds, in order to provide more torque to the engine to quicken acceleration, or do you think this is something that private sector should pursue on its own?

Miss FITZPATRICK. We think that that's something that the private sector now has enough information to pursue if it interests them. They have other alternatives that are coming along. We've talked a little about the automotive gas turbine engine, and they apparently would like to continue with those alternatives instead of trying to make the Sterling engine into something that it isn't now.

Mr. LEWIS. The answer you're giving shows that the engine has the same characteristics as the Wankle engine, the engine used in the Mazda, things of this nature that——

Miss FITZPATRICK. It can readily——

Mr. LEWIS. Automotive interests would be limited, and we'd have to more or less look for a place to use the engine rather than have the engine as a more universal engine.

Miss FITZPATRICK. That's true. It apparently isn't going to be or isn't ready yet for automotive applications. As I said, we think it's a very useful engine for other stationary, steady-state applications.

Mr. LEWIS. In your discussion with Mr. Packard on ceramics, are you looking at the $4 million—that budgeting the 1987 budget—to continue procurement from Japanese? Or just how is that money to be used?

Miss **Fitzpatrick**. No. That would be used for components for American industry, excuse me, American industry component development and fabrication.

It's true that we have obtained some component parts, principally the central rotor of the gas turbine engine, from a Japanese manufacturers; and we also have some rotors from American manufacturers. The Japanese rotor has been tested and run in the engine, and it performs rather well. We haven't yet completed testing on some of the American rotors. I might point out, by the way, that the Japanese were quite willing for us to have that rotor because they don't have an engine like we have to test what the rotor can do. There's a little bit of synergism going on.

Mr. **Lewis**. Are you privy to any of the information as to the temperature limitations of some of their rotating ceramic machinery at this point or——

Miss **Fitzpatrick**. Our engines are designed to go—I believe the Garrett is at 2,400 degrees Fahrenheit and 100,000 revolutions per minute. Is that correct? 25, the Garrett is 2,500 degrees Fahrenheit. The Allison/GM engine is 2,400 degrees Fahrenheit and 80,000 revolutions per minute. The stresses on that rotor at 100,000 revolutions per minute are immense, and that is why that is a particularly crucial and difficult component to fabricate. Also, the engine goes from ambient temperature to about 2,000 degrees in about 4 seconds. So the thermal stress on the ceramic parts is also immense.

Mr. **Lewis**. Does the automotive gas turbine engine rely on ceramic components that are supplied specifically by Japanese companies?

Miss **Fitzpatrick**. No sir. The ceramic components and the engine itself are American made. There is that rotor that we have been testing that is Japanese made. We also have American made rotors.

Mr. **Lewis**. Any further questions, Mr. Packard?

Mr. **Packard**. Thank you. I would like just to pursue one that I didn't pursue, and that is new starts. I just asked a question and dropped it. Are there some projects that are on the shelf, where you would like to see some sponsorship by Government funding, for new starts that you think have greater potential than what we're now doing?

Miss **Fitzpatrick**. We have included in our budget request, we think, the projects that have the greatest potential to answer the country's needs of getting more efficient transportation systems and getting off our dependency on petroleum. Those are absolutely the top priorities.

There would be some—if we had resources available—certainly there are some other tasks that we would like to pursue. But I'd have to say that they are lower priority, either because they are less promising, or because the time to achieve them is much more long range. So we have aimed at the most promising technologies.

I think that the adiabatic diesel program, which would provide a heavy duty large truck engine, is relatively new. We are really in the fairly early stages of that. It's already enjoying some spinoffs. Some of the components and coating work that has been done on thermal coatings is already being picked up by industry to be used in present engines, and they're very hopeful that that will be successful. So the adiabatic diesel engine is itself a rather long-term project and still in its early stages.

Mr. **Packard**. Thank you.

Mr. **Lewis**. Miss Fitzpatrick, what do you envision as any follow-on activities, or what are the follow-on activities you envision for the Gas Turbine Program?

Miss **Fitzpatrick**. We are going to continue with the component development, using the engines that have been built, putting components of different materials and fabrication techniques into those engines, and running them at speed and temperature to see how they hold up. We feel that that is the next step in that engine development, and we have enough money in the budget, $4 million, to carry on that work with one contractor. We would expect some cost-sharing by the contractor.

Mr. **Lewis**. How about——

Miss **Fitzpatrick**. Excuse me. We also have, under our Advanced Materials Program for which we have $6.5 million, a great deal of work on the basic materials of ceramics. How do you design the component? How do you test it? So that is feeding right into both the Adiabatic Diesel Program and the Automotive Gas Turbine Program.

Mr. **Lewis**. So are you saying then that there are some generic types that the ceramic program could use for other than the gas turbine engines?

Miss **Fitzpatrick**. Yes, sir. Yes, sir. We are finding that we expect that ceramics will be useful anywhere where you need high temperature and resistance to corrosion—everything from propulsion systems, to solar collectors, to heat exchangers and heat recouperators, and industrial applications, very wide application for ceramics.

Mr. **Packard**. One additional question, Mr. Chairman.

We haven't discussed or asked much on electric engine potential and electric vehicle potential, and we've obviously dealt with that off and on since the automobile. What is the potential there, in your judgment, in terms of maybe an alternative to the combustion engine?

Miss **Fitzpatrick**. We think the electric vehicle has great potential to achieve our goals. It's very attractive because, obviously, it's a nonpetroleum propulsion system. Not only that, but typically you would expect that electric vehicles would run during the daytime and be charged at night off of the utility system. This means that utility systems themselves would be able to operate more efficiently. It's a form of load-leveling for utilities.

Obviously they are clean, quiet, and have other nice amenities. Our problem has been how do you get them to run with a range that people will find acceptable? If the battery is going to die after 30 miles people aren't going to be happy with that.

Our long-term goal is to develop an engine, I should say a propulsion system, with a battery that would have a range of 200 to 300 miles. We can now run, say, 60, 80, perhaps even 100 miles, on the lead-acid flow battery that we're testing now. The sodium-sulfur battery, we expect, would deliver four to five times the energy capacity of the batteries that we have available to us today. And that is why we are so enthusiastic about the sodium-sulfur battery. We think that it would provide the power capacity—the energy capacity—that we need in order to achieve our goals.

Mr. **Packard**. You're talking about a radical change, of course, in our whole automobile industry. Has there been very much commercial interest in this old/new approach?

Miss **Fitzpatrick**. Yes. Absolutely.

Mr. **Packard**. Not a new, but I mean different approach.

Miss **Fitzpatrick**. No. The General Motors is heavily involved. Ford is involved. Battery and electronics component's manufacturers are in it, Eaton, Eagle Picture, General Electric. There is an organization, called the Electric Vehicle Development Corp., which is made up of, I think, about 50—mainly utilities—who are interested in the development of the electric vehicle. There are test fleets operating around the country which are using the product improvement results which are coming out of our programs and testing them and letting us know how they work. There is a great deal of private investment that is going into this, and I think that the potential is there, and I think that we are on track to achieve it.

Mr. **Packard**. What reaction are you getting on that concept from the oil industry?

Miss **Fitzpatrick**. I don't know, it's just—they haven't sent us any money, but they haven't tried to stop us either—as far as I know.

Mr. **Packard**. Thank you. OK, Mr. Chairman, that's all.

Mr. **Lewis**. Thank you, Mr. Packard.

Now, Miss Fitzpatrick, how does your 1986-87 budget compare to your original plan for ceramics?

Miss **Fitzpatrick**. We had originally asked for about twice as much in 1987 before Gramm-Rudman was passed.

Mr. **Lewis**. The percentages don't work like that. You don't get cut half, but why was it reduced that much?

Miss **Fitzpatrick**. Frankly, that's how much we were given to work with. And what we tried to do was maximize. We were within the total amount. We made the choices about what was to be done with it, and so we tried to pick out the most promising technologies and the best way to use that money.

Mr. **Lewis**. Assuming that you are below the scheduled funding now—which apparently you are—what is not being done? And who is going to pick up the slack?

Miss **Fitzpatrick**. We will not be able to proceed with two contractors on the development of the components and fabrication in the automotive gas turbine engine. With substantial cost-sharing by one or both of the contractors we could do more than—or I should put it the other way around—the more that they are willing to cost-share the more we can get done with the $4 million that we are proposing.

We have reduced—slowed down—our work in ceramics under the Advanced Materials Program—somewhat slowed down. We think we are still on target to work with industry and respond to their needs. As I say, they are becoming much more interested and, to some extent, are playing a little bit of catchup in getting their own capabilities up to speed with what we know how to do.

We are also going to reduce—actually zero out—our support of the Electric Vehicle Test and Evaluation Program. I mentioned that there are a number of private entities around the country who are operating electric vehicle fleets. They have been receiving some support from us in collecting and maintaining their data bases and exchanging that information. We will not be doing direct funding for that. However, one of the main costs that we had in the electric vehicle area for technology transfer was that we sponsored a major conference each year. The private sector is itself sponsoring a conference—major conference—here in Washington—an International Electric Vehicles Conference— and they are paying for it. So there has been a transfer of that burden to the private sector, and they have picked it up quite willingly.

There are a number of other areas, really, in all of our program areas where we could do more. And I won't pretend that there isn't useful work that can be done. We are simply trying to meet the goals that have been established and do our bit on the deficit reduction which we think is also very important.

Mr. PACKARD. Well, let me carry along with what you were talking about, Mr. Lewis, for a minute. Did I understand then that your area is sustaining about a 64 percent decrease from 1986 budget levels?

Miss FITZPATRICK. That's true.

Mr. PACKARD. Which is obviously a greater proportion of the budget reductions, percentage-wise, than many of the other—most of the other—departments are being asked to sustain. Is there a reason why your area and department has been called upon to sustain higher levels of deficit reduction than others in energy or other departments?

Miss FITZPATRICK. No sir, not that I know of.

Mr. PACKARD. The High Temperature Materials Labs are zeroed out. Where are we at on that program?

Miss FITZPATRICK. The funding that has already been appropriated will complete construction of the laboratory. It is scheduled to open early in 1987. The money is also available for equipment, and therefore, we would not, under any circumstances, have been planning to ask for money for construction and equipment. The operating expenses from the department will be coming out of the Office of Energy Research.

The work that will be done in the laboratory is quite broadbased. As I mentioned, the high-temperature materials have applications well beyond the transportation area, and therefore, it was thought better and more appropriate to fund it out of Energy Research than our budget. And it's also a User facility, which is one of its unique values, and so some of the money to support that facility will be coming from the industry people who come to use it.

Mr. PACKARD. Has this stringent budget request affected the personnel in your department?

Miss FITZPATRICK. Yes. We will have a reduction in FTE's—I think it's from 35 to 22.

Mr. PACKARD. Is that going to be done by attrition?

Miss FITZPATRICK. We would hope mostly by attrition.

Mr. **Packard**. I think you'd know that, at least, those of us who still remain here in this hearing feel strongly also about the deficit reduction.

Miss **Fitzpatrick**. Yes, sir.

Mr. **Packard**. And applaud you in your efforts, at least I do, applaud you in your efforts to meet the bench marks that you've been asked to meet. They are rather stringent. And I think, at least I feel, that it's going to take this kind of budgeting process at most levels, if not all, in order to achieve the goals that we are seeking in terms of deficit reduction. I appreciate your efforts.

Miss **Fitzpatrick**. Thank you, sir.

Mr. **Lewis**. Miss Fitzpatrick, how are your programs in ceramics R&D coordinated with other agencies or departments?

Miss **Fitzpatrick**. We have an interagency materials coordinating group which meets regularly—I believe it's every 2 months—every 2 months. And this is a government-wide interagency group, so they share everything that they're doing, what their plans are, what their achievements are, and keep everyone up to speed on the various activities. We also have a group that meets within the Department of Energy because there are several areas, different parts of the Department of Energy, that are working on materials and ceramics.

Mr. **Packard**. Let me ask one other thing that came to mind. These budget bench marks that you have been asked to meet reflect the President's budget proposal, I presume.

Miss **Fitzpatrick**. Yes, sir.

Mr. **Packard**. If the Congress, by choice or by an action, moves to a sequestration how will that affect your budget figures?

Miss **Fitzpatrick**. You mean a sequestration of '86 funds?

Mr. **Packard**. No. We're talking about '87 budget figures aren't we?

Miss **Fitzpatrick**. Oh, I see, later on. Yes. Yes. You mean the 10 or is it 15 percent sequestration that would take effect automatically under Gramm-Rudman?

Mr. **Packard**. Yes.

Miss **Fitzpatrick**. I'm not sure actually. Can I answer that for the record and see whether that——

Mr. **Packard**. You're talking about a 64-percent decrease here.

Miss **Fitzpatrick**. That's right.

Mr. **Packard**. I think this is because of the prioritization process that the President has included in his own budget proposal. Sequestration, of course, is across the board, equal cuts which would change that percentage figure.

Miss **Fitzpatrick**. That's right. The question is, what's the base for the sequestration?

Mr. **Packard**. That's correct. I'm not sure I know that either but——

Miss **Fitzpatrick**. I'm not sure anyone does.

Mr. **Packard** [continuing]. Whatever it is, I think, we could expect that it would be much less than the 64-percent reductions.

Miss **Fitzpatrick**. That's true. If the base is 1986 appropriation and the sequestration is 15 percent—I've seen figures, I'm not sure what it's supposed to be—but that certainly wouldn't amount to a 64 percent reduction.

Mr. **Packard**. Well, in that scenario, if you're going to look at that for the record and present some information—I don't wish to create labor for you—but it might be worthwhile to give us also your priorities if there were additional funds that you would have available—where those funds would tend to go.

Miss **Fitzpatrick**. Yes, sir. We can do that.

Mr. **Packard**. Thank you.

[The information follows:]

PRIORITY ACTIVITIES FOR ADDITIONAL FUNDS

Based on the scenario that the FY 1987 authorization is the FY 1986 appropriation less a 15 percent sequestration, the additional funds i.e., above the Administration's request for FY 1987, would be used to support the following activities, listed in order of priority:

Activity Title	Additional Funds ($000)
Program Direction (7 FTE positions)	$ 460
Advanced Ceramic Materials R&D	4,660
Electric Vehicle Laboratory Testing/R&D Management at INEL	825
ETX-II Single-Shaft a.c. Propulsion System	2,500
Adiabatic Diesel Technology	2,500
Automotive Gas Turbine Component Development	6,000
Vehicle Propulsion Technology Assessment and Transfer	1,500
Alternative Fuels Utilization	240
Capital Equipment for Advanced Materials Development	1,000
High Temperature Materials Laboratory	1,000
Subtotal	$20,685

……

Automotive Stirling Engine Development (No funds were requested by the Administration in FY 1986, but were appropriated by the Congress)	8,000
Total	$28,685

Mr. **Lewis**. Miss Fitzpatrick, what is the distribution for funding for advanced ceramic research in DOA and in the other agencies and departments?

Miss **Fitzpatrick**. Oh, could I answer that for the record, please, Mr. Lewis?

Mr. **Lewis**. Yes.

Miss **Fitzpatrick**. Thank you.

Mr. **Lewis**. Pardon.

Miss **Fitzpatrick**. Could I answer it for the record?

Mr. **Lewis**. Yes.

Miss **Fitzpatrick**. I couldn't give it to you off the top of my head.

[The information follows:]

FUNDING FOR ADVANCED CERAMIC RESEARCH

Estimated funding by government agency for structural ceramics in FY 1985, FY 1986, and FY 1987 is listed below:

Government Agency/Program	Funding ($ in Millions) FY 1985	FY 1986	FY 1987
Department of Energy			
Conservation			
Transportation	17.9	18.7	11.7
Industry	1.7	1.5	.8
Energy Utilization Research	1.8	1.8	1.0
Fossil Energy	1.5	1.2	.9
Energy Research	4.6	4.5	4.5
NASA	5.4	4.5	4.6
National Science Foundation	3.6	3.6	3.7
National Bureau of Standards		2.2	3.0
Department of Defense			
DARPA	9.4	10.0	5.0
U.S. Air Force	4.7	4.7	5.0
U.S. Army	2.5	4.4	4.7
U.S. Navy	1.4	2.3	2.3
TOTAL	54.5	59.4	47.2

Mr. **Lewis**. That would be fine.

Are you all finished Mr. Packard?

Mr. **Packard**. For the fourth time I am finished.

[Laughter.]

Mr. **Lewis**. Thank you.

Mr. Streb, would you like to say anything? You tried but——

Mr. **Streb**. Thank you, Mr. Lewis. I've spoken through the Assistant Secretary here.

Mr. **Lewis**. How about you Doctor?

Dr. **Chiogioji**. No, sir.

Mr. **Lewis**. Well, thank you very much for your very fine testimony.

Miss **Fitzpatrick**. Thank you, Mr. Chairman.

Mr. **Lewis**. Thank you, very much.

[Witnesses excused.]

Mr. **Lewis**. Our next witness will be Daniel Roos, director, Center for Technology, Policy, and Industrial Development, Japan steel industry professor, Massachusetts Institute of Technology.

Well, Dr. Roos, am I saying your name right, sir?

Dr. **Roos**. Yes. You are, sir.

Mr. **Lewis**. Dr. Roos, your testimony will be made upon the written testimony and will be made a permanent part of the record.

STATEMENT OF DR. DANIEL ROOS, DIRECTOR, CENTER FOR TECHNOLOGY, POLICY, AND INDUSTRIAL DEVELOPMENT, JAPAN STEEL INDUSTRY PROFESSOR, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Dr. **Roos**. Thank you very much, Mr. Lewis.

[Chairman Brown returns.]

Dr. **Roos**. It is certainly a pleasure to appear before this subcommittee and to talk some about the auto technology program at the Department of Energy. But, as I indicate in my testimony, I would like to focus primarily on the overall situation of the U.S. auto industry, some of the long-term industry needs, and what the Federal role might be in addressing those needs.

To do that, I'd like to draw, to a large extent, on a large-scale study that has been underway for the last 5 years at MIT. Let me just take a moment and describe that activity. We've organized research teams in all of the major auto producing countries of the world to look at a series of issues revolving around the automobile of international importance. Once a year we then convene a group of about 50 senior officials from industry, government, and labor, roughly one level below CEO. So, for example, from the U.S. members of that group have included Diane Steed, the head of NHTSA; Michael Driggs, who at that time was at the Department of Commerce; group vice-presidents from GM, Ford; chief Wall Street analysts from the auto sector, investment banker, executive vice president of the UAW. The argue being that, if we get those individuals together with their counterparts in Europe and Japan, in an off-the-record setting, we can very much get a better feel and understanding for what some of the issues are that the industry faces. We have those discussions, however, with the benefit of the research that's been performed. So it's not simply an interesting discussion, but we hope it's going to enlighten some of these officials as to what policies they might pursue.

We did publish the results of that first study in this book, which I'm gratified to say "Business Week" named 1 of the 10 best books of the year, The Future Of The Automobile. And although we had planned to terminate the study, we had such encouragement from industry leaders throughout the world that we are now continuing this for another 4-year period.

A lot of my remarks are based on what we observed during the course of the study. My role in that study, and MIT's role, has typically been one of a neutral, trusted arbitrator and really catalyst to try and bring some of these issues forward in an objective manner.

Today, obviously, I'd like to take a somewhat more specific view of the industry from the U.S. perspective. If we look at the industry, in one sense, the news is very good; we had an industry that was mired in a whole series of crises—not only energy, but environmental, safety crisis, in the 1970's. And the statistics are very impressive between 1973 and 1985. The fatality rate per 100,000 miles of travel was cut 40 percent, emissions per vehicle mile from new cars reduced by 50 percent, and fuel efficiency of new vehicles were double. These are very real achievements which the industry can be proud of and which point to what the benefit of available technology can be to tackle clearly identified problems.

However, looked at another way, I believe there is real cause for concern. The American producers have been profitable the last 2 years, but there are a whole series of signs of significant international competition that should cause us great concern.

Imports, once again, account for over 30 percent of sales, and that's in spite of the increases in cost of Japanese cars as a result of the yen-dollar relationship changes. We're having fairly deep discounting by the American producers. The voluntary restraint agreement has been extended another year and still the import penetration continues.

Just last week Hyundai began selling cars in the United States. They are now the top importer in Canada much to everybody's amazement. They draw the Yugoslav's who entered the U.S. market this year. And it's not only the low end of the market. The over $20,000 vehicle is virtually a European monopoly at this point in time. And if one looks at the value—the dollar spent—as opposed to simply the percentage in terms of number of cars, that's a significant amount of money at a very significantly expanding market place.

The Commerce Department has estimated that, by 1988, 17 percent of the cars which have U.S. nameplates on the back will be imported vehicles simply putting the U.S. nameplate on; and of the remaining vehicles assembled in this country last year, 18 percent of those vehicles had foreign components, and one study has just indicated that that will increase to about 30 percent in the next several years.

We also now have a situation where all the major Japanese auto companies have either established, or announced plans for, assembly facilities in the United States. And the estimate is that, by 1990, we will have 1.5 million Japanese cars built in the United States.

The situation does not look like it will improve. There are other developing countries, Taiwan, Mexico, Spain, Brazil, and India who will be shipping considerable volumes of cars and trucks in both the built up form, and we're going to have equally large flows of vehicle parts. The Japanese certainly are moving up scale. This March, Honda will launch its new division, Akora, with two new cars, and the other manufacturers also are producing midsized, larger, more expensive cars for North America.

One could ask how the United States has been able to maintain profitability with this situation. The answer I'd give is a combination of protectionism, primarily the voluntary restraint agreement, and a number of cooperative joint agreements with Japanese producers—the GM/Toyota deal being a prime example—productivity improvements, and creative labor arrangements bringing down the break-even rate level and probably, most significantly, retention of the very profitable middle portion of the market place—the larger size traditional family car.

However, if one looks at the 1985 profits, which just came out in the last several weeks, I'd suggest that's an early warning sign of the fragile health of the industry, and those profits were significantly below 1984.

There's real cause for concern if one starts to add up numbers because we see that the United States is headed towards a situation of overcapacity, which is a situation that the Europeans have had for the last several years, which has had very devastating impact on their auto producers. You have the new Japanese, and I might add, Korean facilities, which are going into the United States and Canada, a Ford plant being built in Mexico, an AMC plant in Canada, the new GMC Saturn plant. You put all that together it's a 30-percent increase in production capability by 1990. You compare that with the growth of the market, which is at best 1 to 3 percent, and one sees you have considerable excess capacity—with the implication being lots of plants are going to close. That's good in a sense. On the other hand, it represents, in all likelihood, a loss of market for the U.S. producers.

In addition to that, the inevitability of an economic downturn and the decrease in vehicle sales causes great concern as to what's going to happen in the event that that downturn occurs—in all likelihood, further cutbacks in investment, employment, and a continuing downturn spiral.

The obvious question is whether there's a way out of this path which can generate new wealth for our country rather than simply protecting activities which are not internationally competitive. I certainly don't pretend to have a definite answer. But I believe, if a way exists, it must be along the path of applying new technology to the products and, in particular, to the production process. Technological leadership will play a significant role in determining who the winners and the losers are, both from company and country points of view, in this international competition.

Investment and technology has always been the historical path for success of U.S. industry and as much evidence that the domestic auto industry is aware of the need to move as rapidly as possible. The Japanese and the Europeans certainly are aware—particularly the Japanese—they see this as the way of the future, and they're investing heavily in new technologies and automated processing. Regaining world leadership in the auto industry, even by playing to our strengths, will not be easy.

There are some optimistic signs if one looks at the U.S. Honda plant and the GM Toyota plant. The quality of the product being produced is equal to Japanese, as is the productivity, and I would suggest that that clearly demonstrates that the United States can be a world class manufacturer if they adequately utilize both new technologies and human resources.

Now what is the relevancy of this to the overall Government and Federal programs in the area of auto technology? I'd suggest, without in any way criticizing the technical accomplishments of existing auto technology activities, that they are largely focused on the issues of the 1970's—particularly in the area of energy efficiency. And while energy crises may recur in the future, and I'll talk about that it a moment, I would suggest there are more pressing problems where Government technology programs might be useful.

If we look at the Government activities, unfortunately, there's a great deal of fragmentation in the auto sector—not just in technology—where DOE, Department of Commerce, EPA, NHTSA, trade representative, NSF, even DOD are all involved. However, there is no clear focus, no agreement on objectives, the policies are generally short term, very domestically oriented, and sometimes conflicting, and unfortunately, we lack a long-term strategy that recognizes the realities of current and future international competition. If we had money and time to pursue many goals at once this might be fine, but unfortunately, we don't have that—as we are all aware.

So what can we do? And I have a few suggestions. First, that we should acknowledge our hard-won successes in the areas of energy efficiency, air quality, and safety were possible because a large amount of technology was readily available to the autoindustry for incorporation into commercial products within a short time. If the industry had to start from scratch developing these things, such as electronics for electronic engine control, we would have had to either restrict auto use or accept dirty air and excessive energy consumption for a long time. There are many other examples, and that's enormously important and a real credit to the programs.

These problems are under control, but we can't be complacent about safety or sanguine that no future energy crises lie ahead. So a Federal role, I believe, must be to work with the motor industry and academic research centers to identify technical problems requiring long-term research of a more basic type which will allow us to make significant technical leaps when the next need arises. Very frequently we don't know when that need will arise. Now the research I'm proposing does not require development of expensive prototypes or other hardware. Therefore, even in an era of budget crises, we should be able to afford a reasonable program of research which gives us a cushion against further energy or environmental crises.

Second, and I'd emphasize the great importance of the coming battleground, the coming battleground for competitiveness and productivity is going to lie in the area of process and design technology. In our research at MIT we have concluded that over the next

20 years, all across the world, semiskilled labor, whether cheap or expensive, will rapidly give way to smart machinery as the key element in competitiveness. Thus, the issue really is not cheap Korean labor nor expensive American labor. Rather, the challenge is rapidly introducing and perfecting new generations of design and process equipment and the complex social systems that must accompany them. Also, as we change the manufacturing process it gives us an opportunity to rethink the whole design of the vehicle itself—of the product.

Now clearly, the major responsibility for this lies with the private sector—particularly with commercialization. However, there is an important role for the public sector since the private sector cannot be expected to assume all responsibility, particularly for generic research, and that role is to drive the frontiers of knowledge.

I believe the major justification and benefit for a federally sponsored autotechnology program should be to increase our knowledge base and intellectual capital. If we're to effectively compete in the autosector we must have a cadre of technically knowledgeable individuals in the public sector, private sector, and academic research community. The Federal Government can serve, and should serve, as a facilitator and catalyst to establish that intellectual infrastructure for appropriate technology deployment.

The question of bringing together Government, university, and industry to identify and overcome the major bottlenecks in technology deployment. However, unfortunately, at the current time, the relationship between those three parties are rather distant—probably a residue of divisive battles of the 1960's and the 1970's—in contrast to Japanese and European situation. We really need to forge an intellectual network between American industry, American Government, and the American university research system to make the best use of the limited research funds we have available. I get concerned sometimes that, as an academic, this is viewed as very abstract and pie in the sky, but I firmly believe that this is the most important thing that this country can do in terms of addressing the issues of international competition.

Now, it follows from this, also, that the Government has to be an intelligent participant in discussions and decisions about technology and the American motor industry. And unfortunately, just at the time that the trend is toward the increased importance of technology we see the Government systematically cutting back from its assessment activities in the autosector from the remarkable level of expertise it possessed at the time of the Chrysler loan. What I fear is a government uninformed about the situation and needs of its largest industry can do more harm than good in trying to help. We had many painful instances of this in the 1960's and 1970's which, unfortunately, we cannot repeat.

Let me urge, therefore, in your deliberations that you take a broad look at the whole picture of the role of the Federal Government for auto technology and the currently suboptimal relationships between Government, industry, and academic research. Our research activities at MIT, which look across the world at trends in autotechnology and support activities of other governments, may be of some assistance in such an inquiry, and we stand ready to help in any way we can.

In summary, the message I've tried to get across is—as this subcommittee is well aware—we are seeing a systematic loss of our mature and high technology industries to international competition. Certainly protectionism is not sufficient to reverse those trends and, in many cases, rewards inefficiency, which further weakens our longrun competitive situation. If we're to compete effectively we have to have a competitive advantage—I'm suggesting that as technology— and the Federal programs are very key in that.

Auto sector certainly has improved dramatically, in a relative sense, in the last 10 years. But unfortunately, that's not sufficient, in an absolute sense, in terms of what world competition is forcing upon us. The Government programs we have now don't reflect the realities of that international competition and need for consistent long-term policies which emphasize technology. The activity suggested should be part of a cooperative effort between public sector, private sector, and the research community that's oriented largely toward development of a knowledge base rather than specific hardware programs, and hopefully this can allow us to maximize the benefits that we will derive from our auto sector.

Mr. Chairman, thank you very much for inviting me today, and I'd be glad to answer any questions.

[The prepared statement of Dr. Roos follows:]

STATEMENT

By

Daniel Roos

Director
Center for Technology, Policy and Industrial Development

Japan Steel Industry Professor

Massachusetts Institute of Technology

Before

The Subcommittee on Transportation, Aviation and Materials

25 February 1986

Mr. Chairman, it is a pleasure to appear before your Subcommittee and comment on automotive technology research and development activities at the U.S. Department of Energy. To do this, I would like to examine the situation of the U.S. auto industry in world competition, to identify long term industry needs and to suggest a Federal role in addressing those needs. However, first, let me identify myself.

I am Director of the Center for Technology, Policy and Industrial Development at MIT. This Center is concerned with how government policy and new technology influence industrial development in an era of intense international competition. Of more direct relevance to today's topic, I am also Director of the International Motor Vehicle Program, a broad-based study of emerging technologies, organizational trends and international issues in the world motor industry. This Program, coordinated through our Center at MIT, involves the direct participation and financial support of all the major motor vehicle producing countries and companies in the world, including the United States government through the Departments of Commerce and Transportation.

A key activity of the Motor Vehicle Program is to bring together, in a neutral forum on an annual basis, senior industry executives, government officials, and labor leaders from all of the countries involved in the international motor industry. In these sessions, we have frank discussions of mutual problems -- sometimes very frank indeed! -- and my role is to be the neutral arbitor. However, today I'd like to take on a different role and focus on the status of the auto industry from a U.S. perspective.

Looked at in one way the news is suprisingly good. An industry mired in energy, environmental, and safety crises in the 1970s -- crises which threatened its long term survival -- has addressed its problems with considerable success. Between 1973 and 1985 the fatality rate per 100,000,000 miles of vehicle travel was cut by 40 percent, emissions per vehicle mile for new cars were reduced by more than 50 percent, and the fuel efficiency of new vehicles was doubled. These achievements are hardly cause for complacency, but they do show what can be accomplished when the industry applies available technology to clearly identified problems.

Looked at another way, there is cause for concern. While the American-based producers have returned to profitability in the last two years, the U.S. auto industry faces intense foreign competition. Imports once again account for over 30% of sales, in spite of price increases of Japanese cars (resulting from a dramatic change in the yen-dollar relationship) and low financing rates or rebates for domestic cars. This month Korea enters the U.S. market, anxious to repeat their Canadian success, where Hyundai is now the leading importer. Import penetration is not limited to the small car segment and the low end of the market. The expanding luxury car market has become practically a European monopoly.

There are other causes of concern. The Commerce Department estimates that by 1988, 17% of the cars with U.S. nameplates will be imported vehicles, and the remaining vehicles, although assembled in the U.S., have a significant amount of foreign components (18% last year). In addition, all major Japanese auto companies have already established or announced plans for assembly facilities in the U.S., so that by 1990 approximately 1.5 million Japanese cars will be built in the U.S. (some on a joint venture basis with U.S. companies).

Furthermore, the import situation is not likely to improve. The entry of Korea and Yugoslavia into the U.S. auto market this year is not an isolated event. Other developing countries such as Taiwan, Mexico and Brazil will soon ship considerable volumes of cars and trucks in a fully built up form, and equally large trade flows in vehicle parts may emerge as well. As the Japanese establish U.S. assembly facilities for small cars, they will reorient their import strategy to a direct assault on the mid- and larger size vehicles, which are the remaining strength of the U.S. industry. The European producers who, like the Japanese, derive their major profits from the North American market, will export even more luxury and semi-luxury units.

With this multidimensional assault, how have the U.S. producers been able to maintain profitability? A combination of protectionism (the Japanese voluntary restraint agreement), cooperative joint venture agreements, productivity improvements and retention of the profitable middle portion of the market place (the traditional larger size family car) have been the primary factors.

However, an early warning sign of the fragile health of the U.S. auto industry is the decreased profits for 1985, despite healthy car sales. Furthermore, North America is headed toward a situation of overcapacity in auto production by 1990. The net effect of new Japanese and Korean facilities in the U.S. and Canada, a Ford plant in Mexico, an AMC plant in Canada and the new GM Saturn plant represent a capacity increase of almost 30%. The U.S. auto market will probably increase at a rate of 1-3% per year, so that an increase of 10-15% at most by 1990 is likely. It is quite possible, however, that some time in the next several years, there will be an economic downturn with an inevitable drop in vehicle sales. If the total market shrinks, it is easy to imagine the U.S. produced faction of domestic motor vehicle sales falling below fifty per cent. This will necessitate further cutbacks in investment and employment and may easily lead to a continuing downward spiral.

Is there a way out of this ratchet of decline -- a path which can generate new wealth for our country rather than simply protecting activities which are not internationally competitive? I do not pretend to have a definitive answer, but I believe that if a way exists, it must be along the path of applying new technology to the product and, in particular, to the production process. Technological leadership will play a significant role in determining which countries and companies are the winners in future international competition. This has been the historical path to success for U.S. industry, and there is much evidence that the domestic industry is aware of the need to move as rapidly as possibly. However, both the Europeans and the Japanese see this as the way of the future as well and are investing heavily in new product technologies and automated processing systems. Regaining world leadership in the auto industry, even by playing to our strengths, will not be easy.

There are some optimistic signs. Not too long ago, many people claimed it was impossible to transfer the Japanese production system to the U.S. because of cultural differences. We now know that system can be replicated. The Honda plant at Marysville, Ohio and the GM-Toyota plant at Fremont, California, to take two examples, are producing Accords and Novas (Corollas) with American workers at quality levels comparable to Japan. Equally important, the productivity of the plants compares favorably with similar plants in Japan. Marysville and Fremont clearly demonstrate that the U.S. can be a world class manufacturer, if the processes and human resources are properly organized and utilized.

Now, Mr. Chairman, what is the relevance of the U.S. government's automotive research and development program to this situation? Without in any way criticizing the technical accomplishments of existing auto technology activities, let me suggest that the government's research activities are focused primarily on the problems of the 1970s, particularly in the area of energy efficiency. While energy crises may well recur in the future -- a point I'll return to in a moment -- there are currently more pressing problems where government technology programs might be helpful.

Unfortunately, the government's overall activities bearing on the auto sector suffer from a lack of focus. In an age of extremely tight resources for government, Federal motor vehicle activities are spread among a number of agencies -- DOE, EPA, NHTSA in DOT, NSF, and even in DOD -- without any clear focus or agreement on objectives. Our auto-related policies are short-term, domestically oriented and sometimes conflicting. We lack a long-term strategy that recognizes the realities of international competition. If we had the money and time to pursue many goals at once, this might be fine, but I believe we do not.

What then can be done in this situation, given, on the one hand, the competitive dilemmas of our largest industry, and on the other -- the fiscal limits on government? Let me suggest the following:

First, we must acknowledge that our hard won successes in the areas of energy efficiency, air quality and safety were possible because a large amount of technology was readily available to the auto industry for incorporation into commercial products within a short time. If the industry had had to start from scratch to develop the electronics for electronic engine controls, for example, we would have had either to restrict auto use or accept dirty air and excessive energy consumption for a very long time. And there are countless other examples.

These problems are now under control, but we cannot be complacent about safety or sanguine that no further energy crises lie ahead. The Federal role, I believe, must be to work with the motor industry and academic research centers to identify those technical problems requiring long-term research of a more basic type which will stand in the way of our making new technical leaps when the need next arises. The research I am proposing does not require the development of expensive prototypes and other hardware. Thus, even in a time of budget crises, we should be able to afford a reasonable program of research which gives us a cushion against future energy or environmental crises.

Second, we must acknowledge that the coming battleground for competitiveness and productivity lies in the area of process and design technology. In our research at MIT we have concluded that over the next twenty years, all across the world, semi-skilled labor, whether cheap or expensive, will rapidly give way to smart machinery as the key element in competitiveness. Thus, neither cheap Korean labor nor expensive American labor is our real problem. Rather, the challenge lies in rapidly introducing and perfecting the new generations of design and process equipment *and* the complex social systems which must accompany them. These changes in the manufacturing process will also enable us to rethink vehicle designand develop new concepts that would not have been feasible with existing manufacturing techniques.

Clearly, major responsibility for technology development rests with the private sector, particularly with regard to commercialization of technology. But the private sector cannot be expected to assume all responsibility, particularly for generic research, that is not directly related to commercial products. There is an appropriate and important Federal role for the government to drive the frontiers of knowledge.

The major justification and benefit of a federally sponsored auto technology program should be to increase our knowledge base and intellectual capital. If we are to effectively compute in the the auto sector, we must have a cadre of technology knowledgable individuals in the public sector, private sector and academic research community. The government can serve as a facilitator and catalyst to establish the intellectual infrastructure for appropriate technology deployment in the auto sector.

Efficient, effective technology deployment involves government-university-industry collaboration in identifying key technological and organizational bottlenecks and jointly attacking them. However, at present the relations between the three parties are rather distant -- in part a residue of the divisive debates of the 1960s and 1970s. We need to forge an intellectual network between American industry, American government, and the American research university system to make the best use of the limited research funds which will be available.

It follows that government must be an intelligent participant in the discussions we should conduct about gaining technological advantage for the American motor industry. Unfortunately, at present the trend is in just the opposite direction as the government systematically cuts back its assessment activities in the auto sector from the remarkable level of expertise it possessed at the time of the Chrysler loan. What I fear is that a government uninformed about the situation and needs of its largest industry can do more harm than good in trying to help. We had many painful instances of this in the 1960s and early 1970s, which we cannot afford to repeat.

Let me urge you, therefore, in your deliberations on the future of the Department of Energy technology research program to take a broader look at the whole picture of American government support for automotive technology and the currently suboptimal relationships between government, industry, and the academic research system. Our research activities at MIT, which look across the world at trends in automotive technology and the support activities of other governments, may be of some assistance in such an inquiry, and we stand ready to help in any way we can.

My message is simple. This Subcommittee is well ware of the loss of both mature and high-tech industries to international competition. Protectionism is not sufficient to reverse the trend and, in many cases, rewards inefficiency, which further weakens our long-run competitive position. If we are to compete effectively, we need public and private initiatives which provide a competitive advantage. Federal programs are particularly important for the auto sector, since it is our largest industry and, therefore, has maximum impact and visibility.

The U.S. auto sector has improved dramatically in the past decade, and industry, labor and government can share in credit for the changes. Unfortunately, those changes are not sufficient to meet the intense competition of the nineties. Existing governmental programs do not reflect the new realities of international competition and the need for consistent long-term policies. Since technology will play a key role in the future, our public sector activities should include a technology component that is oriented primarily toward insuring our knowledge base rather than specific hardware projects. That activity should be part of a cooperative initiative between the public sector, private sector and research community to develop an appropriate technology deployment system which provides a competitive advantage to the U.S. auto industry.

Mr. Chairman, thank you for inviting me here today.

Mr. **Brown**. Thank you very much, Dr. Roos.

I might say that your testimony is excellent. It would be appropriate for the consideration of a number of other subjects which come before this committee involving technology in all of its aspects, but it is particularly appropriate to the particular problems that face us this morning with regard to the support for automotive technology programs in the Department of Energy.

Mr. Packard, do you have any questions?

Mr. **Packard**. Dr. Roos, in your testimony you did feel that we are probably not looking at the long-range picture, that you have some concerns about us being shortsighted in our efforts and, particularly as it relates to technology advancement, in preference to the short-term goals that we have. And yet, at the same time, in the early part of your testimony you mentioned that our research and development programs still are of the 1960's and 1970's generation. Is there a conflict here in your comments? And where should our moneys be going if not in the specific projects that we've discussed earlier this morning?

Dr. Roos. I'm not sure that there is conflict. The point I would emphasize is that if we really take a long-term look then we recognize that the issue of international competition is hugely important. And therefore, we should, to the extent possible, reflect that in terms of what we do with respect to technology; and if we are dealing with very, very scarce resources, then rather than addressing primarily what were the significant issues of the 1960's and 1970's—which were what I suppose I'd call the harmful side-effects of automobile use in terms of the environment safety and energy, those were the key issues—those continue to be issues today, but they are certainly not the key issues in terms of the industry, and it would be very beneficial—and I would suggest necessary—if we are going to preserve a significant domestic auto industry that we reflect in our Federal programs the realities of the current international competition.

Mr. **Packard**. Do you think that we would be more wise in stressing and emphasizing automation types of programs in our manufacturing plants relating to automobiles, or do you think that we ought to be project oriented, as we seem to be now, where we are looking at specific programs and projects.

Dr. Roos. Well, I think you still can be project oriented. But if one looks at the existing programs they all deal with product technology as opposed to process technology—process technology being the manufacturing aspects—and certainly both are experiencing technological leaps forward. But one could argue that the changes with respect to the process are significantly greater than the changes with respect to the product, and somewhat more of a balance might be appropriate in terms of the Federal programs which right now are so heavily oriented toward the product.

Mr. **Packard**. Do you think that other—that our foreign competitors—that their governments are doing more toward this upgrading of the process of manufacturing than we are here in this country in terms of actual dollar commitments?

Dr. Roos. They are doing several things. And the point I would stress is that I don't believe that the significant issue is dollars, even in an era of extremely scarce resources, but rather how those dollars are spent and also the deployment system that's established.

If one looks at the Japanese, it's an extremely tight coupling of industry, of government, and of university research community, and that's an extraordinarily competitive marketplace. One is able to keep that balance where you still have fierce competition in between companies, particularly with respect to the home market, and yet an overall coordination with respect to industry and national goals, and that, unfortunately, is lacking here. We just seem not to be able to relate the various sectors and to be able to utilize our expertise in the best possible way.

One can look at England, and England had an enormous amount of research and a tremendous number of inventions and innovations. But somehow they couldn't get their act together in terms of utilizing that technological edge in creation of new enterprises and putting all the pieces together. And I think that really is one of the key aspects of the Japanese success.

Mr. PACKARD. Do you see, Dr. Roos, a radical shifting and changing of the direction of the automobile industry worldwide in terms of technology, or do you see this being a very gradual transition from the traditional automobiles that we have known since—in my life time? Do you think that we'll see radical changes in the world market?

Dr. ROOS. One has to always be careful when one uses radical change, because it is a relative term. I'll answer that in two ways.

The vehicle that we drive 10 years from now, I think, fundamentally will be very similar in terms of the propulsion system and the appearance of the vehicle, but the way that vehicle is put together will have changed radically. So it will not be that apparent to the consumers. Certainly there will be new materials that will be used.

Probably the most significant change that is impacting both the process and the product is the introduction of microelectronics, computers, and information systems. The automobile, since it came on, has largely been impacted by mechanical innovations. But now, all of a sudden, this industry—which to a large extent was a mature industry from a technology point of view—is being impacted by electronics and computers. And if one looks at process control, you now have flexible manufacturing systems, automated systems—and those totally change the way cars are going to be produced—and that really is a radical change; and one sees it with respect to some of the projects being undertaken, like the Saturn and the Liberty projects by the U.S. companies. But it really is going to restructure how the whole industry works, the relationship between assemblers and suppliers, the whole way we think about putting a car together, and to me that suggests very radical change.

Mr. PACKARD. As foreign competition in the steel industry has emerged—and one of their advantages that they have had as they've built relatively new steel manufacturing plants in foreign countries—they have been able to implement the new technology, in terms of equipment and in terms of fabrication, and that essentially had some serious impacts upon our own rather staid, and obsolete in some cases, steel manufacturing plants here. Do you see now—as new countries coming into the marketplace in automobile manufacturing—a similar problem where they, Korea, and others that are now entering the world marketplace having a newer factory base, comparatively, just being able to implement new technology in the process of manufacturing compared to our old and perhaps outmoded manufacturing plants themselves—the equipment itself—and thus getting an advantage to the point that will have an ongoing and a deeper effect upon future world markets for us, and if so, what is the solution?

Dr. Roos. You posed several questions and let me try and address each of them.

The answer to the first is yes. I think it is a real concern. It's very interesting, however, to look at the Japanese situation because, to a large extent, the Japanese success was based not on technological leadership for technological innovation but more management organizational innovation of how the production process should work. However, over the past several years the Japanese have been making huge profits. Toyota is debt free. That money has been invested in technology. Now one—and since you ain't seen nothing yet—because now the Japanese are first coming on with the results of the investments that they've made in technology.

Now what can be done about it? It's very interesting. When we started our study everybody was saying, "Well, that system can't be transferred to the United States. It's all cultural differences. It works in Japan, but it won't work in the United States." We now see that it will work in the United States. The Honda plant, as I pointed out, in Marysville, which is staffed by American workers, which is not a high technology operation matches roughly the productivity of Japanese plants. We can do it in this country. It's organized by Japanese management, as is the GM Toyota plant. That plant in the United States will be bringing in automation over the next several years.

And that gets me to your other question, "What can we do about it?" What I argue we must do about it is make a serious commitment and investment to technology. That is, as far as I can see, the only area where we have had historically a competitive advantage in the past and where we can maintain that competitive advantage in the future. I think that's particularly true of the electronic technologies. And if we're going to continue to succeed as a nation we absolutely have to commit ourselves to make that investment or else we are simply going to see a continual erosion, not only of this marketplace, but the ripple effect of this industry. Every dollar invested in this industry has at least a dollar and a half of indirect impact on other significant industries in this country—steel and other material industries—you are well aware of that.

Mr. Packard. Mr. Chairman, one more question, if I may. I am well aware that I am over my time.

I just returned—this committee—from Japan and Korea a little over a month ago, and it became obvious that they are going to, Japan particularly, is going to redirect their emphasis in the automobile world marketplace into the midsized, midpriced, and larger cars. They have them there, in fact, they have very few small cars. They shipped them all here, and that was one of the surprises over there—that you don't see a lot of small cars in Japan—not like you do here. They have much larger, much more expensive, $20,000,

$25,000 cars on their highways. And they intend to capture a good deal of that marketplace here, and they are conceding, and they stated that they concede, the small car market to Korea and some of the newer countries that are coming into the marketplace. That will certainly put a great deal more pressure on what you indicated in your testimony as being an open market here—domestic marketplace—in the United States in the midpriced cars. European market has captured, according to your testimony, and has a monopoly on the higher priced cars, and the smaller priced cars the Asian marketplace has dominated. We're leaving open what we consider the midarea. That may change radically with the focus of their market projections. How will that affect the competitiveness of the United States?

Dr. Roos. I think it should be a real concern.

I mentioned Accura, which is the new line of Honda. The reason that it's a new line is that Honda wants it identified as a luxury, high priced product—as opposed to the Civic and the Accord—which have traditionally been more at the low end of the marketplace.

The direct competition that Honda points to is Mercedes and BMW, and they have made it very clear that that is a portion of the market that they want to target. That was done—those products were done—in cooperation with BL (British Leiland). So one has the benefit of some of the European technology and expertise being blended in with the Japanese manufacturing expertise, and one can only expect that they will be very successful in what they do.

Mr. Packard. Thank you, Mr. Chairman.

Mr. Brown. Mr. Lewis.

Mr. Lewis. Thank you, Mr. Chairman.

Doctor, your testimony indicates that you believe the Federal Government's automotive R&D programs are improperly focused. Would you be a little bit more specific, like which programs should we eliminate, should we eliminate the Stirling, AGT, electric vehicle, what have you?

Dr. Roos. It's a difficult situation. I think that when you start programs that are demonstration or development activities that they're started with an expectation of a viable product, and those things typically take a fair amount of time to develop. When you then have a situation, as is obvious here, of budget reductions, in a way you're caught—what do you do—between a rock and a hard place in a sense; because, if you continue the programs to the point where you get a product you've been looking for, you're potentially criticized because you're not focusing in on new issues and new problems. On the other hand, if you cut them off then people come in and say, "Well, my goodness, look at this. We've been working at this for 5 years or 6 years and now we have nothing to show for it." So it's very difficult.

The point I would make, and try to make in my testimony, is that hardware projects are always very, very expensive no matter what we do. And on the other hand, projects that are research projects but not involving development of prototypes—one can go a long way with a relatively small amount of money. And what I would argue for, I think political realism suggests that one is not going to arbitrarily stop a whole set of programs and start a new set of programs, but at least have more of a balance in what is currently being done.

The industry has just changed dramatically over the last 10 years. The problems have changed dramatically, but if one looks at the research activities of DOE they really haven't changed that dramatically. And one can raise questions as to, "Shouldn't there have been a little more responsiveness to the changing set of priorities?"

Mr. **Lewis.** Will you be specific and tell us what type of automotive research development programs that you would support.

Dr. Roos. Well, first, as I've suggested, I think that we should be concerned with the process side as well as the product side and a key there is the computer. And understanding the role that the computer plays, both with respect to the process and the product and I'm talking here of areas such as computer-aided design, computer-aided engineering, computer-aided manufacturing, robotics, flexible manufacturing, all of these things are having and will continue to have a significant impact on the auto sector. We have to continue to be concerned about basic research that goes into the product, processes such as combustion, understanding some of the new materials that are coming along, doing work in those areas becomes very, very important.

Mr. **Lewis.** Do you think that the research and development into ceramics technology is an appropriate role for the Federal Government?

Dr. Roos. Yes, I do.

Mr. **Lewis.** Where do you feel the break point is where private sector should become a partner with the Federal Government in order that the Federal Government should break away from this?

Dr. Roos. Well, I think the private sector ought to be a part right from the beginning. And one ought to have a better process of deciding what the priorities are involving private sector and research community right from inception so that you have the participation in setting some of the goals. This is certainly one of the things that the Japanese do extraordinarily well.

The requirement that the private sector put up matching funds is certainly a good "litmus test" in terms of how serious private sector is about certain areas.

I'm just thinking of an analogy that we had. Maybe I should mention it, because it proves several of the points that we've been talking about in the questioning.

Before directing the center, I was head of the transportation center at MIT, and we looked at the railroad industry, which in some ways similar to the auto industry, was an industry that did not—was somewhat inward looking—the technology was mature. It hadn't been using new technology, and the question was, "What should they do?" and "How should they do it?" And we put together a cooperative program of industry, Government, and universities.

And that happened 10 years ago where industry leaders talked about some of the things that were most important to them. There were projects that were funded at the Federal level, but then as they got very much into an operational stage they passed to the industry, and MIT was heavily involved in this. We did some of the development, tried it out at one railroad, then went and tried it out at five or six other railroads.

One of the most interesting things I found was in looking at the graduates from our program over the 10-year period prior to this research. None of them went into the railroad industry. Absolutely none.

Over the 10-year period that we carried out this program there were some 50 students who were involved in the program. More than half of those students then went and took jobs in the railroad industry and now, as I look around, they are all vice presidents, and some of them have gone into Government, some have gone to the supplier companies. And that's the point that I really wanted to get across—several points—that industry-government-academic community sat down, decided on priorities; priorities changed over the 10-year period. There were cooperative research projects that phased, but probably the most significant benefit was you wound up with 25 or 30 people who were well-trained, who understood the technology, who went on to play leadership roles within the industry. And those people never would have gone into the industry, and that was not a big bucks program, that was program that ran at a level of under $1 million a year, well under $1 million a year. It had really significant benefit. And that same sort of approach of cooperation and diffusion and deployment are really key.

Mr. Lewis. Thank you, doctor.

Thank you, Mr. Chairman.

Mr. Brown. You know, Dr. Roos, the fundamental problem that we're having in trying to develop and support legislation involving this business of maintaining the competitiveness of American industry is political and philosophical.

Why, for example, did the taxpayer's dollar go to fund research in automobile technology or steel technology or electronics technology when we have very large and historically profitable enterprises in these areas? And the trend is toward even larger—the last few years have been marked by mergers—leading to larger and larger concentrations of capital in numerous fields. Why should the taxpayer get involved in this? Why can't the market process do this? In effect, if the steel industry isn't sufficiently interested in its profitability let the steel industry wither on the vine and the capital and management and labor involved there move to some other area which is more profitable and, according to normal economic theory, therefore, making a bigger contribution to the national welfare.

You get involved in that kind of discussion?

Dr. Roos. Oh, all the time. Yes.

Mr. Brown. Well, I think you have to—we have to face it here.

Dr. Roos. Absolutely.

Mr. Brown. Because you see, 10 years ago we were trying to develop this beautiful philosophy you're talking about, joint industry-government cooperation. We've passed the Stevenson-Widler Act. We did a lot of nice things like that which are not going anywhere. All of these programs we're talking about today were passed 10 years ago, and they are not going anywhere—they're getting cut out. But we have to have some sort of a political justification appropriate to today's time.

Dr. Roos. In answer to your question, I think one answer is the degree of concern. And if we had a situation where, as the steel industry went off-shore, we simply moved on to other industries who have U.S. superiority—that would be fine. But we have a situation today where, across the board, we are being subjected to intense foreign competition, and that's true of our high-technology as well as our mature industries.

Certainly we're all familiar with semi-conductors and what's going on there increasingly with Japanese competition in the computer field, and I think we are seriously underestimating what the impact will be there. There's a student who's at MIT who's doing a doctoral thesis on this right now in the semi-conductor and computer industries, and his conclusion is that we have just totally underestimated what the impact of foreign competition is going to be. So we really can't take as a premise that we simply move on to other industries.

I felt, I was going to say interesting—maybe depressing a better word—brought along this week's issue of "Business Week" which is very relevant to the discussion today. It talks about the hollow corporation, a new kind of company evolving in the U.S. manufacturing companies, that does little manufacturing. They simply buy products manufactured by foreign companies and slap a U.S. nameplate on them. And here's good old free enterprise "Business Week" saying, "We've got to do something about this." And what they say is, basically, industrial policy is a dirty word. But, on the other hand, there has to be a public role in this.

And I think the answer to your question is that the play-out of the existing scenario is very, very scary in terms of this country. If one looks at what other countries are doing, they are making the sorts of investments that we're talking about. So just from the viewpoint of survival one can justify it.

Mr. **Brown**. Survival of what, Dr. Roos? These corporations find that it's profitable to put their capital overseas and take advantage of the technology, the labor base, other factors of production, are doing so and continuing to be profitable. The corporate system is global. The market is global. In effect, you're asking us to deny the validity of the corporate free enterprise system and its ability to adapt with what you're suggesting.

Dr. Roos. No, I don't think I am. Many of my remarks are the result of sitting down with CEO's who are pleading for a more level playing field—that there's a real danger, with respect to the corporations, but, I think, a much more significant danger to this country if we lose our manufacturing base.

Mr. **Brown**. What is the danger to this country?

Dr. Roos. The danger is that we start looking like a developing country in many ways. I mean, we have all the characteristics in terms of trade balance, of ownership of enterprises. 1.5 million Japanese cars being assembled in this country might be good from the viewpoint of supplying jobs to a number of people, as opposed to those cars being shipped from Japan, but it also is a little bit scary in terms of the significant ownership of resources, key resources, by foreign corporations.

One can argue that particularly in the auto sector, the industry has really been hit with the whole series of shocks, going back to the 1970's, and has responded extremely well. I think, to a large extent, the free enterprise system has worked. That's the reason that we have profitable auto companies today. They had the energy crisis, the recession, and the invasion of Japanese imports, but we're also talking a fundamental structural change.

Look at the Saturn project. The Saturn project, which represents a rethinking of the product and process, maybe will go online by 1990. When it goes online in 1990 maybe we'll produce half a million cars a year. By 1990 there will be 1.5 million Japanese cars being produced in this country. So then GM has to diffuse—if it works, and if it works by 1990—the results of GM's investment throughout the corporation. The point is that there's an enormously long lead time and an enormously great investment required of corporate America to catch up to the new international competition, and, I think, they're doing a very good job in many respects. The point I would make is they can't do it alone. The situation has changed so radically.

When you compare what one is asking the Federal Government to do, relative to the investment that's being made by corporate America, it's a relatively modest investment. What I was also arguing before was that, whatever was done, should be done with the support and acknowledgement of the private sector. It becomes very important in setting the priorities and the goals and the programs and the particular projects being carried out that the private sector play key roles in determining what those projects are. We've gotten ourselves into a situation where certain things were decided roughly 10 years ago, and then they develop an institutional life of their own, and it's very, very difficult to change and redirect.

If one had a more responsive process by which some of these priorities got set up with the private sector, with the research community playing an active role, then I don't think one would get into the squabbles and questions of, "Should they do this?" or, "Should we do this?" and, "How do we justify it?" I think one would find, as we did with the auto project, there's a surprising consensus. Whereas people thought they were adversaries, they really weren't, but it's getting them all together to agree on those joint goals.

Mr. Brown. You haven't totally resolved the problem. The automobile industry, as you pointed out, in the 1970's didn't feel that they needed any assistance of any sort. They didn't need research assistance, technology assistance, particularly they didn't need regulation that would lead them to higher factors of safety or fuel economy or environmental pollution. They resisted it every stage. They also just about went broke, at least Chrysler did, and the history is that they come in and want Government cooperation when they are about to go broke and face some catastrophe. That's not really a very good basis to establish a relationship.

What I would like to see is an enlightened recognition, on the part of the great corporate enterprise in this country, that we would benefit as a Nation from the kind of patterns that you've described. I don't really feel like continuing to butt my head up against a stone wall, to be honest with you, and I've been doing it for 20 years, and my head's getting a little soft up there. So what do we do to instill or encourage this recognition that our national survival and competitiveness requires some modification of the relationships that have existed in the past and requires it other than in a bail-out kind of a situation?

Dr. Roos. Well, I think you're quite right, Mr. Chairman, in your observations. Let me suggest that, when one does get some of the leaders to sit down together in a nonadversarial setting, that one can get a remarkable agreement on what has to be done. And I'm including labor in here as well as management; and I believe that that's the approach that one should follow, and do that at all levels. Do it at the most senior level, in terms of the CEO's and the heads of some of the Government agencies; and do it at a working level, in terms of some of the research people, and what the technology programs are going to be.

We seem to always get ourselves into these situations of pointing fingers and pinning blame. All of the observations you make are correct. But then, I'll sit down in the board room and listen to a similar set of allegations about the Government, and how they can't get their act together, and how they have all these conflicting short-term policies, and how we gear up for one policy, and the administration changes, and then all of a sudden we have a new set of policies. And can't we have some idea of where we're going and how we're going to get there? You're right and they're right.

I think until we have such an agreement, that's the thing I point out in my testimony, that still we are without a fundamental policy. We are the only country without that policy, and we're the country that both Europe and Japan are looking for in terms of their profits. That's where all the European/Japanese profits are coming from the United States. And so this marketplace is just so important that until we have a better idea of where we're going, how we're going to get there, and then a joint agreement that we're all going to work together on this thing, I think, another 20 years it's going to be banging your head. I agree with you.

Mr. **Brown**. I have no further questions. If any of the staff have any questions——

Thank you very much, Dr. Roos.

You haven't solved many of our problems, but you have illuminated some of them. Thank you.

We will have a second day of hearing on this subject on Thursday, at 10 a.m., in which we will hear some industry views. Maybe we can propound these questions to the industry representatives and see how they respond to it.

The subcommittee will be adjourned.

[Whereupon, at 10:52 a.m., the subcommittee was adjourned.]

FISCAL YEAR 1987 DEPARTMENT OF ENERGY AUTHORIZATION

(Transportation Programs)

THURSDAY, FEBRUARY 27, 1986

House of Representatives,
Committee on Science and Technology,
Subcommittee on Transportation,
Aviation, and Materials,
Washington, DC.

The subcommittee met, pursuant to recess, at 10:05 a.m., in room 2325, Rayburn House Office Building, Hon. Bill Nelson (acting chairman of the subcommittee) presiding.

Mr. Nelson. Good morning. The meeting will come to order.

I regret to say that our chairman's absence is occasioned by his wife being quite seriously ill, and so we will have to proceed this morning without Mr. Brown. Perhaps he will be available a little bit later on.

Today this subcommittee will continue hearings on the 1987 budget proposals for the Department of Energy's transportation program. Last Tuesday, testimony was taken from Department of Energy officials. Today we will hear testimony from those who are directly involved in various DOE research projects currently underway. Specifically, we will hear about the progress on the Stirling engine program, the automotive gas turbine program, electric vehicle battery development, and high-temperature materials research.

The budget proposals for 1987, reflecting 64-percent cut from the amount appropriated for this year, present us with some difficult decisions on the future of transportation research. This committee is not only concerned about looking at specific funding levels of the various programs, but also about assessing future research needs and opportunities, as well as the possible restructuring of DOE's transportation research program to meet the needs and the opportunities.

So we are most grateful for the witnesses who have agreed to assist the subcommittee today in these deliberations. May I turn to the ranking member, Mr. Lewis?

Mr. Lewis. Thank you, Mr. Chairman.

The testimony we heard earlier this week on DOE's transportation program was generally very positive about the success of these programs. I think we all agree that these programs have been useful and the contractors have done an outstanding job of meeting the goals of their programs. In a sense, they have now found that they are victims of their own success.

The administration proposes significant reductions in this area in view of the huge deficits we are facing. In the Gramm-Rudman mandate to reduce those deficits, it is obvious that we have to make some tough choices. It is not going to be enough this year to argue the benefits of a program. I think we have to ask the question, "How far must the Federal Government go in demonstrating a technology before it is reasonable to ask the private sector to pick it up?"

If the technology has merit and the private sector is interested in pursuing it, I think we are going to have to ask them to pay a larger share. We are all concerned with the problems of foreign competition, and I think we would all agree that we want a level playing field for our own industry, but we simply cannot respond to every threat of foreign competition by spending millions of Federal dollars to demonstrate every promising technology to the point where no risk remains for industry.

I know the choices we have to make will not be easy. Nonetheless, the responsibility is ours. I hope the testimony we will hear this morning will help us make some very difficult decisions.

Thank you, Mr. Chairman.

Mr. **Nelson**. Thank you, Mr. Lewis.

Mr. Nightingale and Mr. Goldwater. Please, if you will, proceed. Thank you for being with us.

STATEMENT OF NOEL P. NIGHTINGALE, DIRECTOR OF PROGRAMS, STIRLING ENGINE SYSTEMS DIVISION, MECHANICAL TECHNOLOGY, INC., ACCOMPANIED BY MR. GOLDWATER, VICE PRESIDENT AND GENERAL MANAGER, STIRLING ENGINE SYSTEMS DIVISION

Mr. **Nightingale**. Thank you, Mr. Chairman.

Accompanying me this morning is Mr. Goldwater, the vice president and general manager of the Stirling Engine Systems Division at MTI.

I have presented a full testimony for the record, and I would like to summarize that testimony for you this morning.

Mr. **Nelson**. We appreciate it.

Mr. **Nightingale**. I would like to touch upon the status of the ASE Development Program, discuss a few of the spinoff programs that are starting to evolve from our work, present you with some of the intelligence we know of the activity in Japan on Stirling development, and then touch upon a Stirling engine technology program which we feel will enable us to keep the lead in this valuable technology.

Just to focus my discussion around the two major goals of the work that we have done, which was to develop an automotive Stirling engine for you and our country, and to transfer that Stirling engine technology to the United States and give us a lead in that, this is a picture of the Mod II. It is in fact at test now, and I thought you would appreciate a three-dimensional photo like that.

This is a picture of the Mod II which has been designed specifically to fit inside a General Motors Celebrity, which is an A-body, front-wheel drive car. The radiator there is in the front, and that's how the installation looks under the hood of a car.

The status within the program is that the Mod II engine design has been completely designed, hardware has been manufactured, and we in fact—as we promised you last year—started the test in January 1986. The Mod II is projected to give us 41 miles per gallon combined, and an acceleration of from 0 to 60 miles-per-hour in 12½ seconds.

If I can dwell a moment on the mileage figures, that graph is a picture of the mileage that we obtained in our earlier testing with the Mod I engines in the program, where we were obtaining about 24 miles per gallon. After some testing at the GM lab we were able to incorporate some of the Mod II technologies into that engine, so that we managed to increase that mileage up to 28. That gives us the confidence that our Mod II will, in fact, meet the 41 miles per gallon projection that we are using, simply because the upgraded Mod I to this date has reached about 22 percent above the IC.

Another point about this curve is, you can see how the industry has done in terms of their mileage. The Celebrity with the spark-ignition engine in it has 31 miles per gallon, whereas older cars like the Spirit were as low as 23 miles per gallon. You can see how the competition has certainly improved as well.

The next slide, you cannot talk about mileage without really addressing acceleration or "performance" as we like to use it, vehicle performance. The major criteria used to measure performance is the time taken to accelerate from 0 to 60 miles per hour. Earlier in the program, certainly one of the criticisms against Stirling engines was that they were heavy relative to their power size, and that certainly showed up in these types of data—the acceleration times of 28 to 26 seconds. It wasn't until we got into microelectronics and into the control system of the Mod I and the Mod II that we were able to bring that acceleration down to around 16 seconds, and so we feel fairly confident that the Mod II will perform as we have projected and be competitive with the spark-ignition engine.

Another major point relative to our status is that we have maintained, at the will of Congress, the schedule, and the technical milestones that we have promised you over the past. The program is on schedule to be completed in fiscal year 1987. To emphasize that fact, I present you with a schedule which I presented at my testimony last year in which I indicated that the engine would be at test this year. I think this graph also shows you that all of our efforts from here to the end of the program will be devoted toward developing the Mod II engine and demonstrating the program goals in September 1987.

We continue to also develop valuable life and reliability off the Mod I engines in the program. I think that life and reliability are important parameters as far as industry is concerned.

The next graph shows the increase in engine hours that we have been able to obtain off the Stirling. These hours were on our Mod I engines. Of course, the Mod II has just started to test.

That gives you a pretty good assessment of where we are in meeting the first goal, which was to develop an automotive Stirling engine. The second goal, which was to transfer that technology to the United States, really started with our initial relationship with

United Stirling of Sweden, who had the technology at the beginning of this program, back in 1978. That technology has assuredly been transferred to the USA team of NASA-Lewis and MTI. The Mod II was completely designed and procured here in the United States.

Through some of the comments that I will make now, you will see also that that technology transfer is now being passed on to a USA manufacturer and to some potential product users. The USA manufacturer involved is Deere and Company. During the past 12 months, I am pleased to report that they did participate in the development of the Mod II engine block, and cost shared to the effect of 25 percent in that effort. We are now in the process of establishing them as a subcontractor to manufacture, assemble, and test one of the Mod II engines in the program, so I think that John Deere does offer a very important base for the possible commercialization of this product.

This is a picture of the Mod II block as cast by John Deere that I made reference to.

The previous viewgraph that I showed really displays the fact that technology transfer is a process, and the end user is really the person who needs to be made aware of the virtures of the Stirling engine technology. We have two spinoff programs that have occurred in the last 12 months which give us a great deal of confidence that the commercialization process is taking shape.

The first one involved the U.S Air Force and NASA, and the application is for a maintenance van on the flight line. The participants in that program are Deere and Company, who will be cofunding their efforts, Purolator, and the American Trucking Association. The real interest on the part of the Air Force is the fact that the engine will use the JP-4 aircraft fuel that they use in the aircraft and it makes the logistics a little bit easier for them, and the projected lower maintenance costs associated with the Stirling engine. I should emphasis that that van program is funded by NASA technology utilization funds and does not come out of any DOE funding.

Another program which, again, is funded by the Army, is the use of a Stirling engine in a 25-kilowatt generator set. The attractive features of the engine here are, of course, its multifuel capability—they can use diesel or any kind of fuel they would get their hands on in a battle scenario—the quiet operation, and the difficulty in detecting a Stirling engine while it's running because of its low exhaust temperatures. The exhaust temperatures of a Stirling are about half that of a diesel.

Deere and Company offer the potential for a follow-on program with the Army where they would, in fact, manufacture the engine for that program.

So I think that we are starting to see commercialization reality here, and it's difficult for me to crystal ball exactly where it will end up but I would have to say that utility vans or generator sets are probably small markets to which the Stirling engine may be applied before the actual automobile application, which is a very difficult market to penetrate.

Let me just comment a little on what I feel are the results of the technology and the leadership that we have obtained through this program in Stirling engine technology. We have a professional engineering staff at MTI that is eager and ready to transfer the technology to industry. As you can see from the spinoff programs, we are starting to get some non-Government money support, and there are other nonautomotive applications that we are seeing this technology applied to.

The foreign competition is strong. We have done some intelligence of the activities, particularly in Japan, and we have identified a number of industrial, Government, and university participants. This is simply a list of the companies and the agencies who are all working on Stirling engine development in Japan. I myself and Mr. Goldwater plan to visit Japan in 4 weeks to see firsthand.

There are some rather interesting names up there. Aisin Seiki we know is a division of Toyota. They have put a Stirling engine on a Toyota car and run acceleration and mileage tests. Asahi Glass is a ceramic company, and they have built ceramic Stirling engines, so there are a number of activities going on in Japan that we know of.

This is also a graphic from a report obtained in Japan, and it confirms the subcommittee's original identification that the Stirling engine technology for a passenger car is indeed the most difficult, not only from a practical product development point of view but from a marketability point of view, and we have certainly found that out. That high level of technology that we have now obtained by virtue of your support in this program enables the application to be applied for air conditioning and power generation, as we know the Japanese are targeting their products for.

So, in summary, I would like to recommend to the subcommittee that the ASE development program be authorized for $8 million for fiscal year 1987 in order to complete the program on schedule, as we have promised, and that I think in order to keep this technology lead, that a technology development program similar to the types of technology programs we have had in the gas turbine and diesel areas over the past be initiated so that we can allow the process of commercialization to take form in the country while we maintain our leadership in this technology.

The concludes my summary of my testimony, Mr. Chairman, and I would be quite happy to answer any questions you may have.

[The prepared statement of Mr. Nightingale follows:]

HEARINGS ON
DOE TRANSPORTATION PROGRAMS

Subcommittee on Transportation, Aviation, and Materials
Committee on Science and Technology
U.S. House of Representatives

Automotive Stirling Engine Development Program

Presented by:
Noel P. Nightingale
Director of Programs
Stirling Engine Systems Division

February 27, 1986

MECHANICAL TECHNOLOGY INC.

About the Author . . .

Noel P. Nightingale

Mr. Noel Nightingale is the Director of Programs at the Stirling Engine Systems Division of Mechanical Technology Incorporated, Latham, New York, a high-technology research, development, and manufacturing company. He has managed the ASE program almost since its inception in 1978 and has authored various papers on its progress. He has also been instrumental in transferring Stirling technology to industry and product users during the past few years. Prior to that, he was employed for more than 12 years with Pratt & Whitney Aircraft, a division of United Technologies Corporation. During that period, he undertook technical and managerial roles in the design, analysis, and development of military and commercial gas turbines and large (100 MW) ground power units. He also has management experience in multinational consortiums and aircraft maintenance. Mr. Nightingale holds a Bachelor Degree in Mechanical Engineering from the University of Toronto and Master Degrees in Engineering Science and Business Administration from Rensselaer Polytechnic Institute.

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TESTIMONY ON THE AUTOMOTIVE STIRLING ENGINE DEVELOPMENT PROGRAM
before
Subcommittee on Transportation, Aviation, and Materials
Committee on Science and Technology
U.S. House of Representatives

Mr. Chairman, members of the subcommittee, my name is Noel Nightingale, and I am the director of programs at the Stirling Engine Systems Division (SESD) of Mechanical Technology Incorporated (MTI). The Automotive Stirling Engine (ASE) Development Program is funded and managed by the Department of Energy (DOE). The NASA-Lewis Research Center located in Cleveland, Ohio, is responsible for the project management of the program. MTI is the prime contractor on the program. MTI is a high-technology research, development, and manufacturing company located primarily in the state of New York, with wholly owned subsidiaries in Michigan and California. The SESD engages approximately 120 people in the development of Stirling engines for a variety of applications. This team, primarily professionals, was formed by MTI in response to the national need for an advanced energy-efficient technology, in this case, the Stirling engine.

Mr. Chairman, MTI appreciates the opportunity to appear before this subcommittee to testify on the ASE development program. It is my pleasure to report that the ASE program continues to achieve its technical goals, while remaining on schedule and within budget. The program is on target for the development of a Mod II engine and the final demonstration of the overall program goals in FY87.

My testimony reports on the status of the ASE program in meeting its two goals which are to:

- Develop an automotive Stirling engine and
- Transfer Stirling engine technology to the United States.

In addition, I shall comment on the increased participation of industry and potential product users in the program. I will also comment on a proposed Stirling Engine Technology Program to follow the completion of the ASE Development Program to ensure that the United States maintain the lead in this important technology. Comments will also be made on Stirling engine developments in Japan. Finally, I will close with a set of conclusions and recommendations. All figures referenced in the text are included, for your convenience, in numerical order at the end of this testimony.

BACKGROUND

In Section 302(b) of Public Law 95-238, the United States Congress charged the DOE with initiating programs leading to the development of advanced automotive propulsion systems. DOE selected two basic engine cycles: the gas turbine and the Stirling. The Stirling engine was selected because of its intrinsic capability to provide high cycle efficiency; i.e., when installed in an automobile, the Stirling engine can attain a higher fuel economy than that of conventional power systems. Further, since the engine uses a continuously burning external combustion system, it is capable of using a variety of liquid fuels while maintaining low emission and noise levels.

The logic set forth in the program was to develop two experimental engines in sequence. The first engine, the Mod I, was a new engine design based on Stirling engine technology as it existed at the beginning of the program in 1978. The second engine, the Mod II, was to incorporate technology advancements made during the course of the ASE program and was to demonstrate the program objectives. The program is currently entering its final phase; the Mod II design has been completed and the first engine is being tested.

The ASE program has a number of specific objectives stemming from the public law. They are:

- A 30% improvement in fuel economy over a comparable production spark-ignition engine
- Operation within strict emissions standards ($NO_x \leq 0.4$, $HC \leq 0.41$, $CO \leq 3.4$ grams/mile, and particulates ≤ 0.2 grams/mile)
- Interchangeable operation on a variety of liquid fuels
- Reliability and life expectancy comparable to commercial engines
- Initial cost and life-cycle cost competitive with conventional engines
- Acceleration suitable for safety and consumer considerations
- Noise characteristics meeting Federal Standards.

SUMMARY

Although the time frame and magnitude of the ASE program have been altered by budget restrictions over the past years, progress toward the goals and objectives has not waivered. The 15 million dollars authorized by this committee last year and supported by the Congress enabled us to complete the design and procurement of the Mod II engine. MTI has done its utmost to meet the will of Congress by maintaining the schedule of the program and, as promised, MTI is requesting authorization of the 8 million dollars that was indicated last year as necessary to complete the program in FY87.

Significant progress has been made during the past year in transferring Stirling engine technology developed under the ASE program to industry and other potential users of the product. Deere and Company has participated as a cofunding subcontractor and in this the final phase of the ASE program is planning to manufacture, assemble, and test a Mod II engine. A program to assess the merits of a Stirling engine installed in an Air Force maintenance van has been initiated. Monetary support for this Van Program comes from NASA technology utilization funds, which are aimed at commercialization, and from Deere and Company, who will actively participate in the program and cofund their expenses.

Purolator and the American Trucking Association are also participants in the Van Program. Purolator is evaluating the lower maintenance costs of the Stirling, since the company uses a fleet of vans for its business. Both Purolator and the American Trucking Association are interested in the higher fuel economy of the engine. In another separate program, the Army is studying the use of the Stirling engine in a 25-kW generator set. A unit is currently undergoing tests at an Army site. The ASE program plays a critical role in supporting these demonstration programs by loaning out Mod I engines that are no longer in use in the ASE program.

Programs involving product users and engine manufacturers are critical to the ultimate commercialization of Stirling engines. Such programs are also crucial to ensuring that the United States keep its technology edge over foreign competition which has given high priority to the continued development of Stirling engine technology. To protect our current status and to allow the maturity of Stirling technology to take place, it is recommended that a Stirling Technology Program be initiated and authorized for 4 million dollars in FY87, simultaneous with the closure of the ASE Development Program. This recommendation is in keeping with past practices of Government to support the continuation of gas turbine and diesel engine technology until commercialization had taken place in the industrial sector.

BENEFITS OF THE ASE PROGRAM

To achieve national acceptance, a Stirling engine developed for the automotive application must be capable of meeting a number of stringent requirements. It must be small enough to fit within the structure of current vehicles, which are becoming more and more streamlined each year. It must provide sufficient power to meet the demanding performance requirement of today's cars. It must be efficient over a wide range of power and speed by providing high fuel economy both in the stop-and-go environment of city driving and the constant-speed cruising of highway driving. But most importantly, it must be inexpensive to manufacture in order to provide manufacturers an economical advantage to penetrate existing markets, as well as an incentive to develop new market sources. It must be inexpensive to operate in order to provide users an economical reason for choosing a new technology that does not dislocate their spending habits. Until the creation of the Mod II, Stirling engines were unable to meet these requirements; but through the technology developed under the ASE program, they can be met. Industry and users are only now becoming aware of this fact.

The wisdom of Congress in deciding to develop the Stirling engine for the automotive application, as opposed to other applications, continues to be confirmed. A high level of technology is required to develop an automotive Stirling engine and the goals are difficult to achieve. Once the goals are achieved, however, there are almost immediate windfall benefits to other applications. Examples include light-duty and heavy-duty vehicles, generator sets, irrigation pumps, solar electric units, heat pumps, industrial prime movers, submarines and other marine applications, and farm equipment. Whereas the free fallout of ASE technology to other applications may be a somewhat subjective assessment, it serves to underscore a key national benefit - that the ASE program provides the United States with a core technology having a host of spin-off applications. These, in turn, can provide our nation with a greater capability for conserving energy, as well as maintaining the technological leadership in those areas.

The payoff of introducing Stirling technology into the United States is a vast potential for new jobs related to new products, their manufacture and service, as well as an increase in associated trade employment. The multifuel capability of the Stirling engine will provide personal and national security in times of petroleum dislocation. The Stirling engine will meet the emission standards defined in the Clean Air Act, thereby contributing to the national effort to upgrade our environment. The ASE also provides an advantage to improving our noise environment, since the noise level emitted from a Stirling engine is much lower than that of conventional engines...a Stirling engine requires neither a catalytic converter nor a muffler. Finally, the overall potential for conserving valuable fuel resources through the use of more efficient Stirling engines in automobiles and in other applications is immense.

1985 ACCOMPLISHMENTS

During 1985, significant progress was made toward the program goals. The Mod II design was completed and engine hardware procured. The first Mod II was tested, as scheduled, in January 1986. Critical technologies were further developed during the year, resulting in improvements in vehicle fuel economy and performance while demonstrating increased life and reliability. An engine manufacturer, Deere and Company, became actively involved in the program and cofunded expenses. And finally, two demonstration programs were initiated through the loan of Mod I Stirling engines from the ASE program. In one of these programs, a 25-kW generator set was assembled and is being tested at an Army site. In the other, a maintenance van will be prepared for test at an Air Force base. Both of these programs are funded through separate sources. These activities are more fully described under "Spin-Off Programs."

Mod II Engine

The Mod II engine was designed to meet the program goal of providing a highly efficient automotive power plant with a competitive manufacturing cost. During the past year, the detailed design of the Mod II engine was completed. Figure 1 is a photograph of the Mod II engine showing its compact size. The Mod II was designed for installation in a GM Celebrity sedan. A picture of the Mod II installed in the engine compartment of a Celebrity is shown in Figure 2. As equipped by GM, the Celebrity obtains 26 miles per gallon in urban driving and 40 miles per gallon in highway driving conditions, yielding a combined mileage of 31 miles per gallon. With the Mod II engine installed, the Celebrity is projected to obtain 33 miles per gallon in urban driving and 58 miles per gallon in highway driving, yielding a combined mileage of 41 miles per gallon. This is 32% above that of the spark-ignition engine. All mileage quoted is for unleaded gasoline.

These projections are based on experience to date with the Mod I and Upgraded Mod I Stirling engines, which provides confidence for the Mod II. For example, Figure 3 compares the actual combined vehicle mileage achieved with the Mod I and Upgraded Mod I Stirling engines and the combined mileage expected for the Mod II. The figure shows that the Upgraded Mod I achieved a 22% fuel economy improvement above that of the spark-ignition engine installed in the same vehicle. The projection for a 32% improvement with the Mod II over the spark-ignition engine is therefore very reasonable.

Comparisons of fuel economy should not be made, however, without a simultaneous comparison of vehicle performance. The major criterion used to measure vehicle performance is the time required for a car to accelerate from stop to 60 miles per hour. This response provides a measure of the power generated by the engine in relationship to the weight of the vehicle. The generally accepted automotive industry standard is to accelerate to 60 miles per hour in 15 seconds, although there is considerable variation among models. Until recently, vehicle performance impeded the Stirling engine from competing with spark-ignition engines. The Stirling engine was excessively heavy and exhibited poor transient characteristics, as compared to its maximum power level.

The Stirling engines used early in the program delivered an acceleration time of 36 seconds. The Mod I installed in an AMC Concord accelerated in 28 seconds, and an early upgraded Mod I engine installed in an AMC Spirit accelerated in 26 seconds. It was not until specific Mod II technologies were incorporated into the Upgraded Mod I engine that the acceleration time was reduced to 16 seconds. This level of performance provides confidence in the predicted acceleration for the Mod II of 12.5 seconds, as compared to the spark-ignition engine (Celebrity) acceleration of 13 seconds. Figure 4 depicts graphically the improved acceleration time achieved in Stirling engines over the course of the program.

Only three Mod II engines will be manufactured under the ASE Development Program, given current funding levels. During the past year, Mod II engine hardware was procured for the two engines scheduled to be built by MTI. Deere and Company will procure and build the third Mod II engine. The first engine assembly began in late 1985 and it was tested for the first time in January 1986. The schedule shown in Figure 5 was also presented during testimony to this subcommittee a year ago. It is shown again to emphasize the fact that the Mod II schedule has been maintained and to show that the remainder of the program will be devoted to testing and developing the Mod II engine. A Celebrity will be prepared and equipped with a Mod II engine to demonstrate the program objectives by the end of FY87. The requested FY87 authorization of 8 million dollars will be used to support this work. Two photographs of the first Mod II engine are presented as Figures 6 and 7. Figure 6 portrays the engine partially assembled with the four pistons protruding above the engine block. Figure 7 is a photograph of the fully assembled engine mounted in MTI's test cell.

Stirling Engine Reliability

During the past year, Mod I engines continued to develop useful life and reliability data while undergoing extensive testing. Figure 8 shows that during the past year, 5716 test hours were obtained on Mod I engines bringing the total accumulated level to 14,397 hours. Such testing has yielded valuable information on the life and reliability of seals, materials, and combustors. In addition, it has yielded data on the formation of emissions and soot during transient operations such as engine start-up and vehicle acceleration. If industry and consumers are expected to accept the Stirling engine, they must be convinced of its reliability through thousands of test hours. Warranty claims and maintenance costs are prohibitively high when products are found to be unreliable. This fact alone constitutes sufficient reason for continued, active testing of the Mod I engines in the program.

Engine Manufacturer

The second goal of the ASE program is to transfer Stirling engine technology to the United States. It has been MTI's intention that to involve an engine manufacturer in the activities of the program would be the most expedient means of accomplishing this goal. During the course of the program, we have gained notice and respect from industry. Their reaction has changed from negative to positive, yet without commitment. It is with great pride, Mr. Chairman, that I am able to report to you that Deere and Company has participated in the ASE program during the past year, cofunding their expenses at a rate of 25%, and that they will perform as a subcontractor to manufacture, assemble and test one Mod II engine during the remainder of the program.

One of the major parts designed into the Mod II that contributes to its lower cost and compact size is its single-piece engine block. Compared to engine blocks used for spark-ignition engines, a Stirling engine block is more complex because it houses many internal passages that must be absolutely leak proof. Manufacturing the Mod II block required extensive casting development, which Deere and Company willingly did at their own expense. Figure 9 is a picture of the Mod II engine block casting developed by them. The view shows the cylinder cavities that house the engine pistons.

It is felt that the active involvement of Deere and Company is the single most important reason to substantiate our requested authorization for FY87 to complete the ASE Development Program. Their involvement provides the mechanism to pursue commercialization of the engine and ultimate return to the Government of the money invested in the ASE program.

Spin-Off Programs

Two programs have been initiated that utilize Mod I engines borrowed from the ASE program. One program centers around the use of a maintenance van by the Air Force on aircraft flight lines. Such vans are used to transport men and materials from service hangars to aircraft parked on the lines. Vans experience considerable stop and start operation and rarely are required to travel above 30 miles per hour. Current vans are powered by diesel engines. The Stirling is an attractive power plant for this application in that it can accept the same fuel (JP-4) as used in the aircraft. The program spans three years and is supported by NASA technology utilization funds, since it is intended to lead to commercialization. Participants include the current NASA/Lewis and MTI team, as well as Deere and Company, Purolator, and the American Trucking Association. Deere and Company is funding a portion of the program.

The second program is centered around the demonstration of a Mod I Stirling engine in a military 25-kW generator set. The active participants in this program are NASA/Lewis, MTI, and the Army. A Mod I engine borrowed from the ASE program was installed in an Army generator set normally powered by a diesel engine. The unit is currently going through performance tests conducted by the Army. It will be followed by 500 hours of endurance testing. The Stirling engine is appealing for this application because of its multifuel capability and quiet operation. Another attractive aspect is its low-temperature exhaust which makes a Stirling engine unit more difficult to detect. It is anticipated that after the initial demonstration, a field test program involving many Stirling-powered generator sets will be put in place. It is expected that Deere and Company would manufacture the engine units for the program, making use of the knowledge gained from manufacturing a Mod II engine in the ASE program.

Stirling Technology Program

The United States possesses a distinct lead in Stirling engine technology over the remainder of the world by virtue of the achievements made in the ASE program. This lead should continue to be secure if we, as a nation, continue to develop Stirling engine technology. Also, the breadth of the engine's application is already apparent, as evidenced through the interest shown by Deere and Company and the spin-off programs discussed above. It is the technological lead already attained and concern for the future economic security of this nation that prompts MTI to recommend and request an authorization of 4 million dollars for a follow-on Stirling Engine Technology Program in FY87.

MTI is very proud of the accomplishments made within the ASE program. The technology of the Stirling engine has clearly been advanced to the point where it is no longer a laboratory curiosity but rather a viable alternative power plant ready to enter prototype and preproduction development. Even though the manufacturing cost, specific weight, and specific volume have been reduced to levels competitive with spark-ignition and diesel engines, there are weaknesses where the technology requires further development. Certainly the use of cost-effective ceramics in the design of the engine is required. Although ceramic technology development has been part of the ASE program, the use of ceramics has not been fully explored because of lead time and funding restrictions. Also, the combustion control system has not been sufficiently developed to allow its use with alternative fuels.

Emphasis was placed on the use of unleaded gasoline for the automotive Mod II demonstration. Whereas the use of alternative fuels has been demonstrated, knowledge of the specifics of properly controlling the operation of the engine is incomplete. Likewise, the long-term corrosive and errosive effects on combustion system materials are not known. Lastly, the engine has demonstrated adequate life and reliability at normal ambient temperatures but has not been fully developed to operate satisfactorily at temperatures in the vicinity of -20°F.

Quite logically, one may ask why these shortcomings exist. These technological difficulties take more time to overcome than the ASE program has been able to afford. The emphasis has been on demonstrating fuel economy and emission objectives. When comparing the money spent to date on Stirling engine development to the billions of dollars invested in the development of other engine systems, it is not surprising that some technical weaknesses still exist.

Mr. Chairman, this committee and, indeed, all of Congress should be complimented for their foresight in authorizing and supporting the continuation of the ASE program over the past years. The nation has benefited from your direction as it has available a new technology which allows flexibility in our consumption of various energy forms. And, it is a technology for which the United States possesses a distinct lead over every other nation. However, the effort should not be stopped, since other nations, particularly Japan, are quickly accelerating their efforts in this field. Within the United States, one engine manufacturer and a few other product users are just becoming actively involved in assessing and utilizing Stirling technology. By virtue of the ASE Development Program, a critical organization is in place at MTI capable of transferring Stirling technology to them, which is a primary program goal.

Therefore, Mr. Chairman, it is hoped that the same foresight that obliged this committee to initiate and support the ASE program will cause it to continue to keep the United States in the lead on Stirling technology. Authorization to continue development of the Stirling engine via the recommended Stirling Technology Program beginning in FY87 will accomplish this goal. Such an approach is not without precedent. In the past, the Government has been supportive of both gas turbine and diesel engine technology programs in order to keep the United States at the forefront of those technologies.

Stirling Engine Development in Japan

Nearly 70% of the primary energy requirements in Japan rely on imported petroleum. Although the supply and demand for oil is currently stable, the long-range scenario for a stable supply is doubtful. The development of new nonpetroleum engines and the technical development of energy-conserving equipment has been recognized as necessary. A large-scale Japanese research and development project entitled "Stirling Engines for Wide Use" was set up and started in 1982. This was part of an energy conservation program named "Moon Light Project" at Japan's Agency of Industrial Science and Technology (AIST), Ministry of International and Trade Industry (MITI). Total funding is nearly 10 billion yen (50 million U.S. dollars) for the six-year Stirling engine development effort authorized through FY87.

The Stirling engine project objective is to realize 3-kW and 30-kW class engines with high efficiency, low emissions and multifuel capability. Engine test demonstrations are to be made in FY87 for use in heat pump power plants to heat and air condition both residential and commercial buildings. In addition, engine test demonstrations will be made on industrial and construction machinery. This includes electric power generation. Four industrial companies participate in the program: Mitsubishi Electric Corporation, Toshiba Electric Corporation, Aisin Seiki Company and Tokyo Sanyo Electric Company. From a review of available literature, it is our opinion that all efforts have been directed toward the development of the Stirling engine with little or no system development. If this assessment is correct, it is our opinion that the United States has at least a three-year lead on the technology.

In addition, MTI has been able to ascertain the status of other Japanese nongovernment-sponsored Stirling engine development. The front runners in a listing of some sixteen industrial firms named as investigating various applications of the Stirling engine appear to be the following. Aisin Seiki formed a separate group to install a Stirling engine in a Toyota for demonstration purposes. The Asahi Glass Company has developed ceramics for Stirling engines and is currently developing a second-generation engine. The Sanden Corporation is developing a 2.5-kW Stirling engine for application in a residential heat pump that they plan to commercialize in 1987.

Japanese university and government agency activities include as a minimum: Tokyo Institute of Technology, Ceramic Material Development and Analysis; University of Tokyo, combustion and analysis; Meiji University, application studies and heat transfer; Agency of Science and Technology, analysis; and the National Aerospace Laboratory, combustion.

Conclusions

Based upon the points raised in this testimony, Mr. Chairman, I would like to summarize with the following conclusions:

1. The Mod II Stirling engine will meet the goal of Title III of Public Law 95-238 to develop an alternative automotive power plant.

2. The ASE program has accomplished the second goal of the program by transferring Stirling engine technology to the United States - the Mod II was designed and manufactured in America.

3. MTI has carried out the will of Congress by continuing to conduct the ASE program on schedule, while meeting the technical milestones and objectives requested and funded.

4. The foresight of Congress and, in particular, this committee in supporting the continuaton of the ASE Development Program in the past years was borne out this year when a major engine manufacturer entered the program, and two major spin-off programs emerged involving product users.

5. Technology transfer, the process whereby product users become aware of a technology, is beginning to occur for the Stirling engine.

    a. To discontinue the development of Stirling engines would stop this process.

    b. Through demonstration programs, the advantages of Stirling technology will be proven, and the product user will then create a demand for the technology.

6. Associated with the success of the ASE Development Program, and already in place is a dedicated team of professionals prepared to translate their knowledge to American industry and to product users. Without the continuation of the ASE program and the support of the U.S. Government, the solidarity of this team will be compromised.

7. Through the foresight of Congress, the United States has attained a worldwide leadership in Stirling engine technology for a broad range of applications in addition to the automotive field. The attention and support given by foreign governments and industries to Stirling engine technology threaten this leadership.

8. The first market in which the Stirling engine will be commercialized may not be the automotive field because of the inherently high warranty risks. Rather, it is more likely to be commercialized in a special market segment where product development can continue without major impact. Two likely candidate markets are utility vans and generator sets. These commercialization efforts will be choked off unless Stirling technology continues to be developed.

Recommendations

With the foregoing conclusions in mind, Mr. Chairman, I would like to make two major recommendations. I recommend that the ASE Development Program be authorized to continue through FY87 to complete the demonstration of the program objectives and to allow further progress in transferring Stirling technology to American industry and product users.

Secondly, I recommend that a Stirling Engine Technology Program be initiated in FY87 to allow for the continued advancement in Stirling engine technology to occur as precedented by Government's role in the past in maintaining American leadership in gas turbine and diesel technology.

Thank you, Mr. Chairman, for the opportunity to appear before this important committee, and may I offer to answer any questions at this time.

Figure 1 Mod II Stirling Engine - 80 hp

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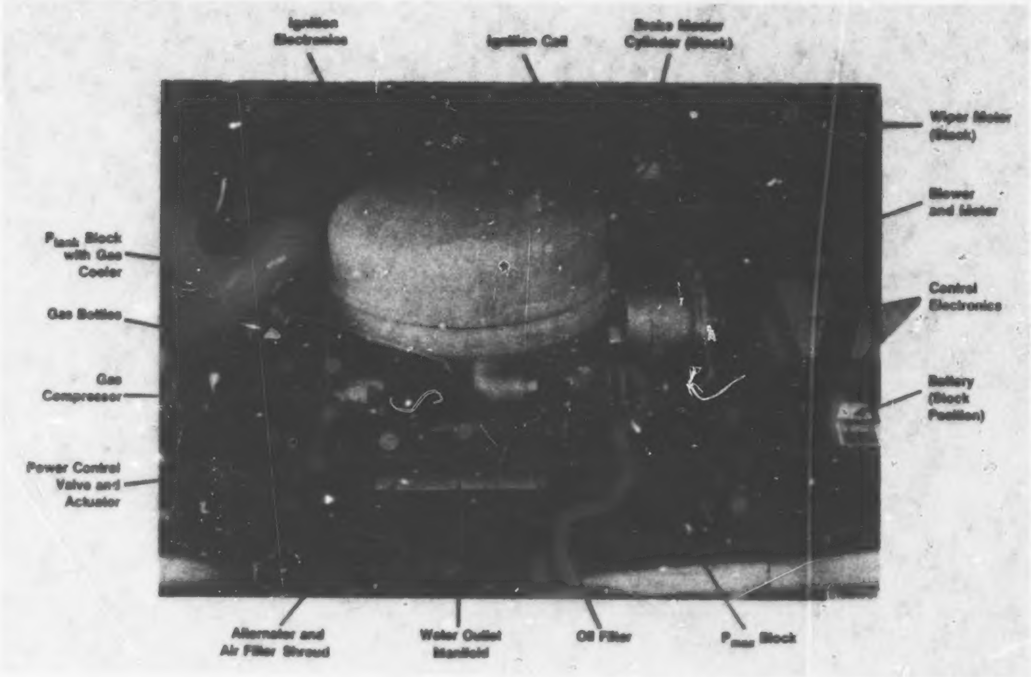

Ignition Electronics
Ignition Coil
Brake Master Cylinder (Block)
Wiper Motor (Block)
Blower and Motor
Control Electronics
Battery (Block Position)
P_{tank} Block with Gas Cooler
Gas Bottles
Gas Compressor
Power Control Valve and Actuator
Alternator and Air Filter Shroud
Water Outlet Manifold
Oil Filter
P_{max} Block

Figure 2 Mod II Celebrity Installation; Upper Front View

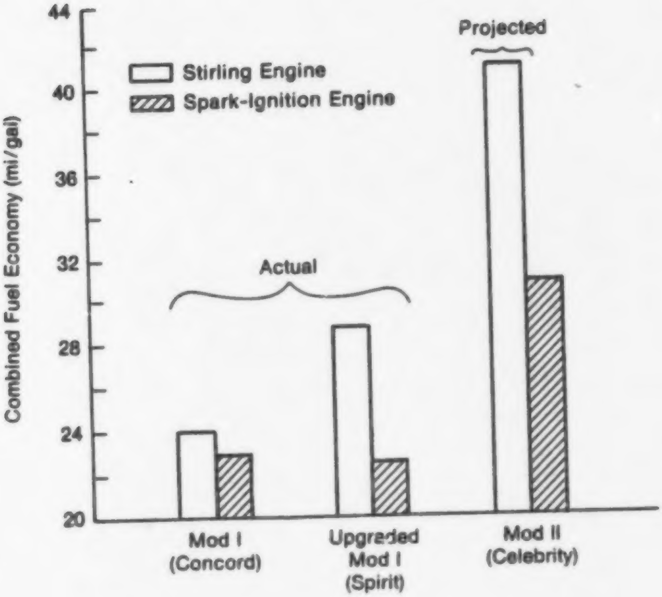


Figure 3 Stirling Engine Combined Mileage Compared to Spark-Ignition Engine

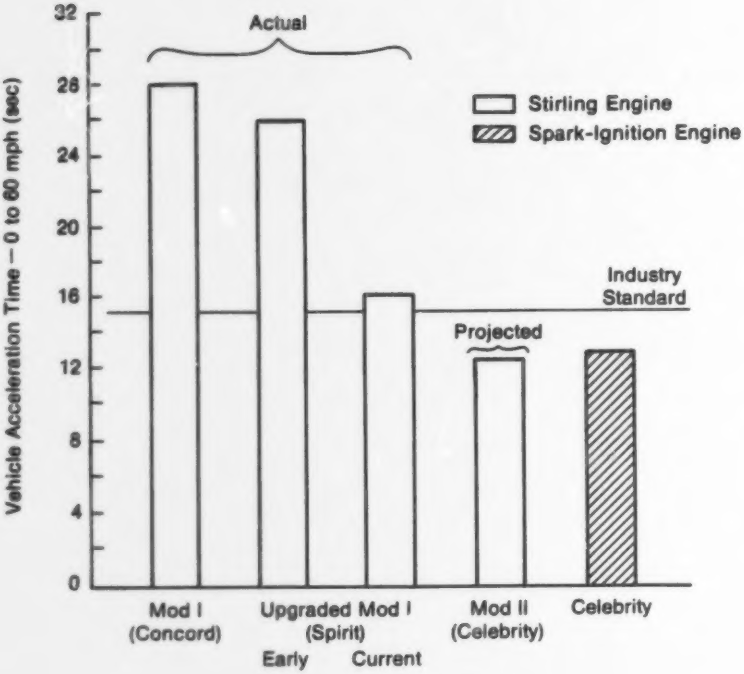


Figure 4 Stirling Engine Acceleration Compared to Spark-Ignition Engine

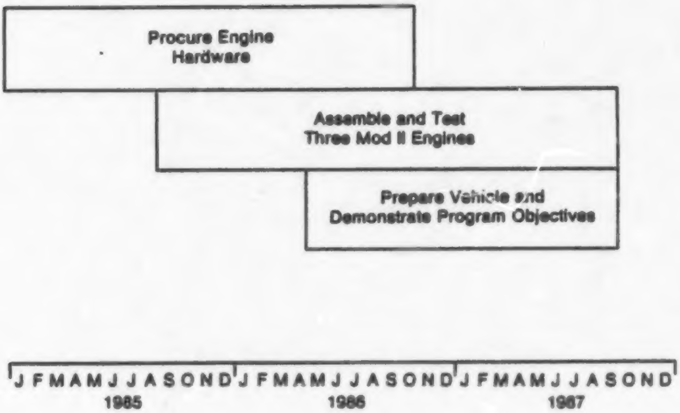


Figure 5 ASE Program Schedule: Mod II Engine Development

Piston
Engine Block

Figure 6 Partially Assembled Mod II Stirling Engine

Figure 7 Mod II Engine Installed in Test Cell

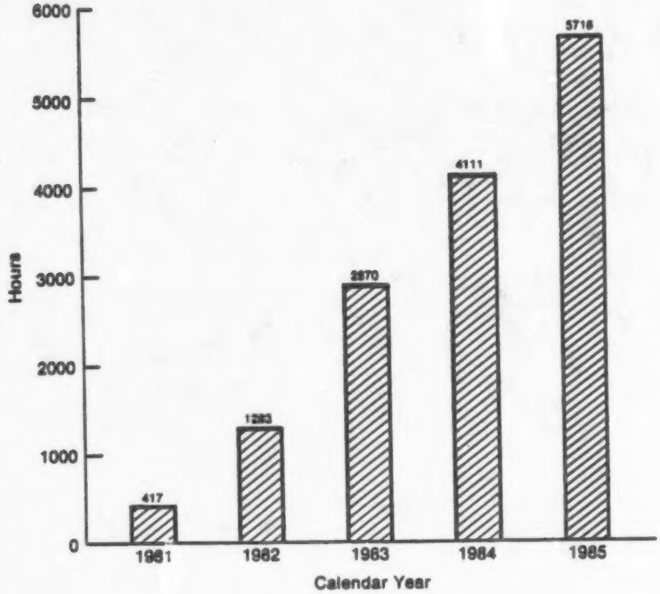


Figure 8 Mod I Stirling Engine Test Hours

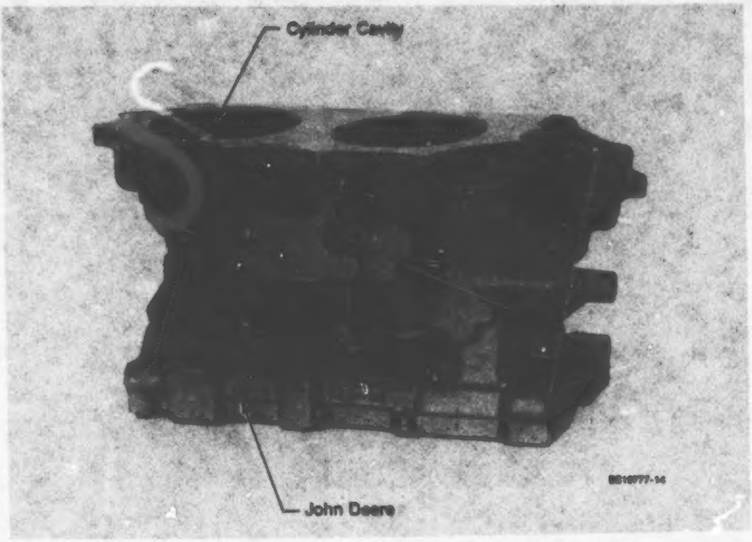

Cylinder Cavity
John Deere

Figure 9 Mod II Engine Block Casting

OUTLINE

- ASE Development Program
- Spin-Off Programs
- Stirling Engine Development Activities in Japan
- Stirling Engine Technology Program

ASE Development Program

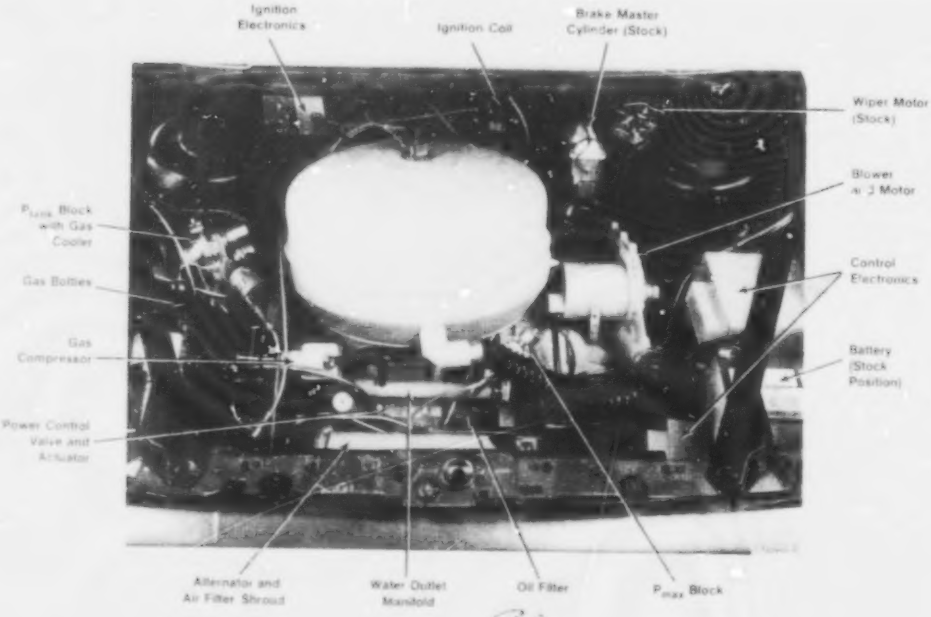
GOALS

- Develop an Automotive Stirling Engine
- Transfer Stirling Engine Technology to the United States

MOD II STIRLING ENGINE
(80 hp)

MOD II CELEBRITY INSTALLATION

(Upper Front View)


Ignition Electronics
Ignition Coil
Brake Master Cylinder (Stock)
Wiper Motor (Stock)
Blower and Motor
Control Electronics
Battery (Stock Position)
P_{tank} Block with Gas Cooler
Gas Bottles
Gas Compressor
Power Control Valve and Actuator
Alternator and Air Filter Shroud
Water Outlet Manifold
Oil Filter
P_{max} Block

ASE Development Program

STATUS

- Mod II Automotive Stirling Engine Design Completed
  - Hardware Manufactured in United States
  - Testing Started January 1986
  - Combined Mileage Projected at 41 mpg
  - Acceleration Predicted at 12.5 Seconds

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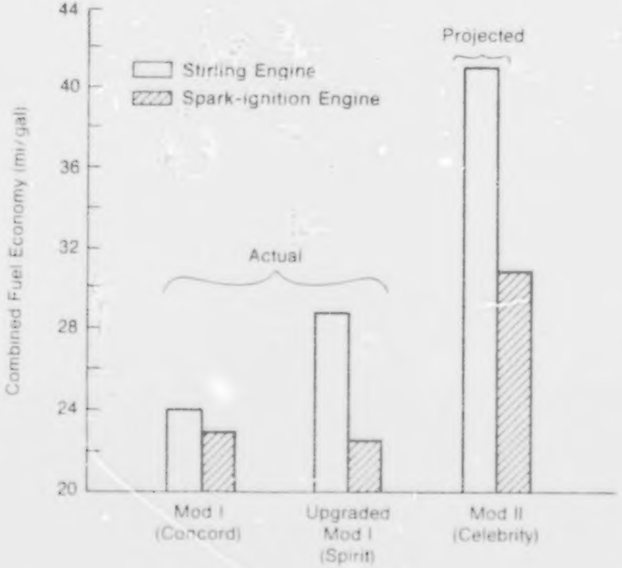
STIRLING ENGINE COMBINED MILEAGE COMPARED TO SPARK-IGNITION ENGINE



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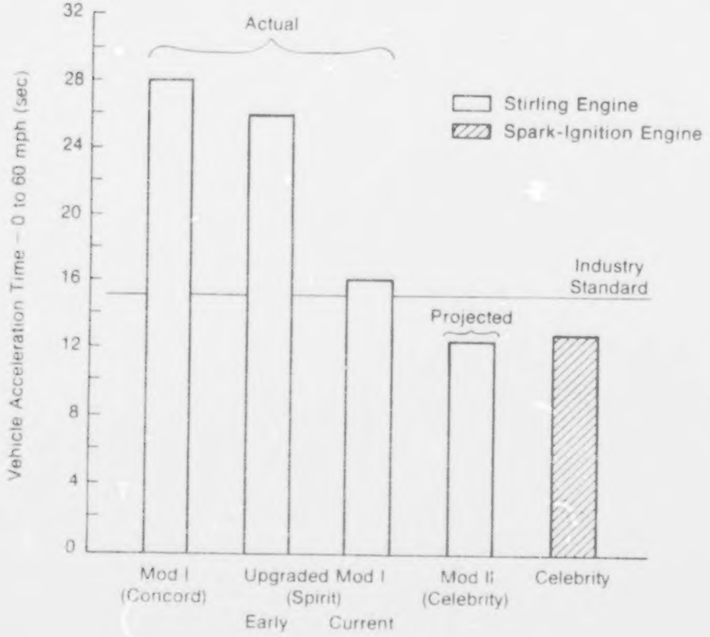
STIRLING ENGINE ACCELERATION COMPARED TO SPARK-IGNITION ENGINE



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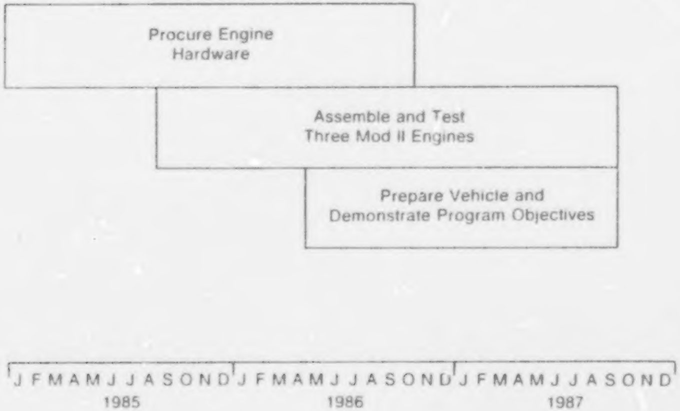
ASE Development Program

STATUS

- Technical Milestones Completed on Schedule and within Budget
  - Program on Schedule to Be Completed in FY 87

ASE PROGRAM SCHEDULE:
MOD II ENGINE DEVELOPMENT



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ASE Development Program

STATUS

- Stirling Engines Continue to Demonstrate Life and Reliability

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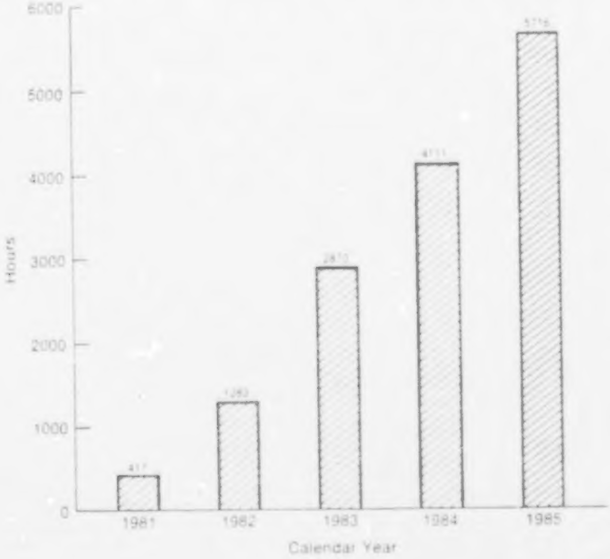
MOD I STIRLING ENGINE TEST HOURS



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ASE Development Program

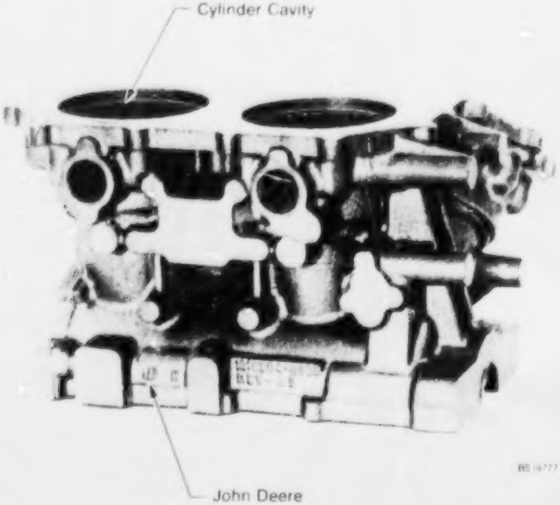
TECHNOLOGY TRANSFER

- United Stirling of Sweden
  - ↘ U.S.A. NASA/Lewis-MTI Team
    - ↘ U.S.A. Manufacturers and Product Users

— Deere and Company

- 25% Company Funds Invested in Engine Block Casting Development
- Subcontractor to Manufacture, Assemble, and Test Mod II Engine
- Engine Commercialization Potential

MOD II ENGINE BLOCK CASTING


Cylinder Cavity
John Deere

BS 18777-14

Spin-Off Programs

USAF/NASA VAN PROGRAM
(NASA Technology Utilization Funds)

- Program Participants
  - — Deere and Company (Cofunding)
  - — Purolator
  - — American Trucking Association
- Engine Features of Interest
  - — Fuel Flexibility: JP-4 Aircraft Fuel
  - — Lower Maintenance Costs

Spin-Off Programs

ARMY/NASA 25-kW GENERATOR SET PROGRAM

- Engine Features of Interest
  - Multifuel Capability
  - Quiet Operation
  - Difficulty in Detecting Low-Temperature Exhaust
- Deere and Company, Potential Manufacturer of Engine Units

86104

COMMERCIALIZATION REALITY

- Utility Vans
- Generator Sets
- Automobiles

WORLDWIDE STIRLING TECHNOLOGY STATUS

- U.S.A. Leadership Position
  - Professional Engineering Nucleus at MTI
  - Nongovernment Monetary Support Initiated
  - Increasing Interest in Nonautomotive Applications
- Foreign Competition Strong
  - Industrial, Government, and University Involvement in Japan

86106

JAPANESE STIRLING ENGINE DEVELOPMENT

Industrial, Government, University Participants

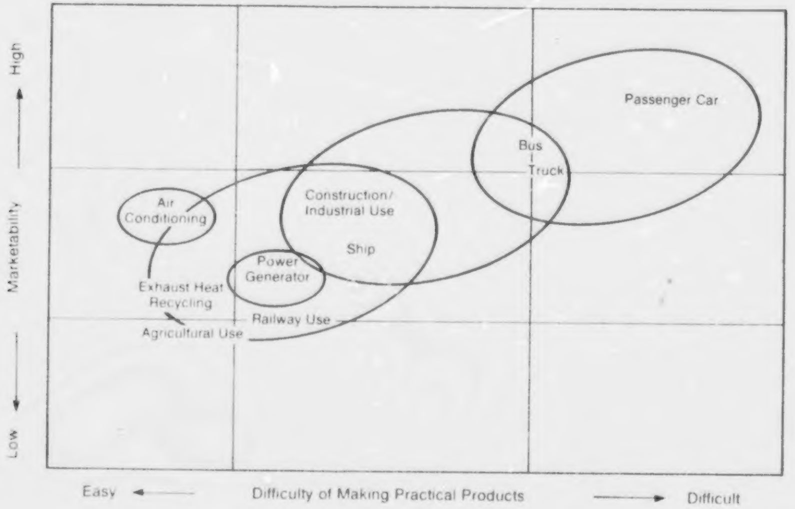
Industrial Companies

- Aisin Seiki
- Asahi Glass
- Daihatsu Diesel
- Fuji Heavy Industries, Subaru Technical Headquarters
- Kawasaki Heavy Industries
- Kokujo Kanagata Kogyo
- Matsushita Electric Industrial Co. Central Research Laboratory
- Mitsubishi Electric
- Mitsubishi Heavy Industries, Nagasaki Laboratory
- Mitsui Engineering and Shipbuilding
- Nippon Piston Ring
- Nissan Motor Company
- Sanden Corp.
- Tokyo Gas, Technology Laboratory
- Tokyo Sanyo Electric
- Toshiba
- Yanmar Diesel Engine

Government Laboratories/Research Institutes/Universities

- Japan Automobile Research Institute (JARI)
- Japan Gas Association
- Japan Society of Industrial Machinery Manufacturers
- Kanazawa University
- Mechanical Engineering Laboratory
- Meiji University
- National Aerospace Laboratory
- National Research Institute for Pollution and Resources
- New Energy Development Organization (NEDO)
- Nihon University
- Science University of Tokyo
- Ship Research Institute
- Shipbuilding Research Association of Japan
- Tohoku Gakuin University
- Tokyo Institute of Technology
- University of Tokyo

RELATIONSHIP BETWEEN MARKETABILITY AND DIFFICULTY OF MAKING PRACTICAL STIRLING ENGINE PRODUCTS



FORWARD IMPETUS

- ASE Development Program
  - FY 87 Authorization of $8 Million
  - Needed to Complete Program
- Stirling Engine Technology Program
  - FY 87 Authorization of $4 Million
  - Needed to Maintain Technology Leadership

Mr. Nelson. Thank you, Mr. Nightingale.

Mr. Lewis.

Mr. Lewis. Yes; I am wondering, Mr. Nightingale, how this engine compares with other small engines in the production market today, with the torque requirements. It's a high RPM engine, apparently, but the zero to 60 miles per hour in 12½ seconds, you showed on your graph other spark ignitions. What were you comparing that with, what other kind of engines?

Mr. Nightingale. Basically all of those comparisons are with spark ignition engines.

Mr. Lewis. But what type? Give me an engine that you were comparing it with.

Mr. Nightingale. An 80 horsepower Pontiac 4-cylinder engine that you would basically buy in a Pontiac showroom.

Mr. Lewis. What will be the impact on your program of the proposed deferral in 1986?

Mr. Nightingale. The deferral is going to cause a very serious destruction of our engineering staff. There is really no way around that. Maybe Mr. Goldwater would like to elaborate on that answer.

Mr. Goldwater. Yes, sir. We would see a major layoff of the engineering resource that has been built in this country on Stirling engines.

Mr. Lewis. Can you tell us what interest that the Japanese have shown in the MTI engine?

Mr. Goldwater. Sure. We have had a number of companies visit us at MTI for a variety of applications. In particular on the automotive program, a company has visited us recently that has indicated a need for about a $50 million program to develop the Mod II to production, and they have discussed this program with us.

Mr. Lewis. How much money is actually needed to complete the program? Do you have any idea how much money you will need to complete the program?

Mr. Nightingale. The deferral has taken away $4.4 million from MTI, and we need the $8 million in 1987. That's $12.4 million, and I feel quite confident that we can meet everything that we promised you.

Mr. Lewis. What would be the benefit of funding both our AGT teams in the ceramic follow-on component program? Do you have any idea on that? I can wait for the other panel.

Mr. Goldwater. Yes. I would suggest that the AGT people answer that question, sir.

Mr. Lewis. Can you tell us what interest other companies in Detroit have shown in the Stirling engine, such as Chrysler, American Motors, Ford, or GM?

Mr. Nightingale. As we reported last year, we had a relatively successful relationship with the General Motors Research Lab in testing our earlier Mod I equipped in the Spirit, and at the research labs on a technical basis they are extremely interested and open to us coming there and sharing with them testing and data and so forth, but as far as a corporation commitment, there is none.

We have a similar relationship with the Ford folks. We have given them the data at a technical level but, again, there is no corporate commitment.

Mr. LEWIS. You mentioned in your presentation the Japanese work on a Stirling engine. Do they operate under a license from you, or do they——

Mr. NIGHTINGALE. No.

Mr. LEWIS. Not at all?

Mr. NIGHTINGALE. No. Their funding, as we can gather, comes from two sources. One is private, internally, like a company like Sandin, and the other funding source is from the Moon Light project, which was a multimillion-dollar program to develop energy, alternative energy technologies in the country, and they are getting money through the Government.

Mr. GOLDWATER. Excuse me. To expand on that, the program is, from 1982 to 1988, sponsored by MITI at about a $50 million level.

Mr. LEWIS. I see. If you have the full $8 million for 1987 and the $4.4 million, are you going to be back asking for additional money in fiscal 1988, or is this really going to complete the program?

Mr. NIGHTINGALE. That will complete the program, the ASE development program——

Mr. LEWIS. And you will no longer need any Federal money?

Mr. NIGHTINGALE. As I recommended, I feel that there is a technology base here that needs to be worked on, but as far as the basic Mod II engine development program is concerned and the development of the engine as a product, no.

Mr. LEWIS. One final question: I heard testimony on Tuesday that apparently no American car companies were really that interested in the Stirling engine. Can you respond to that?

Mr. NIGHTINGALE. They haven't made any commitments at any high level, and I feel that the technology is still far off in terms of meeting their short-term goals and they are not in a position to put any financing into it.

Fortunately, we have come across a company in John Deere who feel that the future is there in Stirling, and they are starting to analyze the engine from a manufacturing point of view, but the automotive industry per se—you are quite correct—has not shown any interest at this point.

Mr. LEWIS. Is this not where the largest area of production would be, for American cars or Japanese cars?

Mr. GOLDWATER. Yes, it would. The obvious problem is that the Stirling engine, which shows dramatic increases in fuel economy, is not the driving force today in the automotive market because obviously the oil prices are dropping, gasoline prices are dropping, and the automotive companies are not in a position and they are not interested in putting a new engine in their vehicles if they don't have to.

Mr. PACKARD. Would the gentleman yield on that?

Mr. LEWIS. I yield.

Mr. PACKARD. Because I was very interested in the same question and attended the same hearing, and I understood that the reason that it didn't have good—or that the automobile industry wasn't all that interested was because it didn't have good application to automobile use. It doesn't have high torque. It performs, I understood, much more efficiently under stationary levels like a water pump or a generator, rather than the requirements of the automobile. Now I would be interested in your response.

Mr. Nightingale. Yes, Mr. Packard, I can comment on that. That was true 3 or 4 years ago. That's a statement made by somebody who hasn't stayed close to the technology. We have moved the technology so quickly in this program that we have been able to counteract that criticism on the Stirling engine.

The best point I could make would be to point to the acceleration times that I showed you. It certainly applied in past years where we had 28-second, 26-second acceleration times. Now it's down to 16, 15, which is the industry standard, and that's a reflection of the microcomputer control and the complex control technology that we have developed in the engine. In fact, it is that technology that I feel we have a 3- or 4-year lead on the Japanese. From what I can read in their papers, they have not been able to address the transient nature of the engine.

Mr. Packard. I thank the gentleman for yielding.

Mr. Lewis. Thank you.

Thank you, Mr. Chairman.

Thank you, Mr. Nightingale.

Mr. Nelson. Thank you.

Mr. Packard.

Mr. Packard. Thank you.

Obviously the Japanese are very interested in what is going on with the Stirling engine, from your chart. What kind of technology transfer has there been available to the Japanese companies from this research project?

Mr. Nightingale. I think that they have, though Government brochures and rpeorts which are open to the public, they have had the advantage of seeing cross sections of the engine. They have been able to see pictures of components that we have developed in the course of the program, and when you take a look at the cross sections of their engines, they are very, very similar to the engines that we have developed here under this program, and so we see some similarity.

Mr. Packard. In your research programs, do you address at all the protection of technology that we and the private sector are expending?

Mr. Nightingale. Yes.

Mr. Packard. And do you develop recommendations as to what can be done to protect the technology?

Mr. Nightingale. Yes, we do, Mr. Packard. We in fact stamp and mark protectable and sensitive drawings, reports, as such that they are not allowed to be released to the public.

Mr. Goldwater. Excuse me. To expand on that, Mr. Packard, we also have a protfolio of patents that have come from the automotive Stirling program and retained in the United States.

Mr. Packard. You are aware, however, that most countries don't honor U.S. patents, Japan included?

Mr. Goldwater. Well, that's very possible, sure. Of course, it is our only protection against technology.

Mr. Packard. I guess that's what we are looking for. It's not the discussion at this hearing, but certainly we are looking to find ways to get international protection for patents and for technology information.

Mr. GOLDWATER. If I may also comment—excuse me, sir—the difficulty in the release of technical reports is the ability of another source to look at where we've been, determine where not to go, and then to put their resources in the direction that is, of course, the successful direction. That cuts their development time and costs dramatically.

Mr. PACKARD. The trucking industry has shown some interest. Does the trucking—does the engine have more application, from your experiments thus far, to trucking and truck motors than it does to the routine automobile motors, or so you see a difference in that area?

Mr. NIGHTINGALE. Yes, there is a slight difference, and the advantages of the Stirling at the very high power levels for large trucks is not as profound as you see here in the mileage curves here for a passenger car. The large-size diesels have been developed very thoroughly for high efficiency and high mileages for the application.

However, we have been able to identify a unique feature of the Stirling engine which can be used—in a term called "bottoming cycle"—which would take the hot exhaust of the diesel and pass it through a suplementary Stirling engine, and you can increase the mileage by 12 percent. We did that study with the Cummins Engine Co., and they are currently looking at the Mod II for that application, but again, that is something that has not evolved into any commercialization effort yet.

Mr. PACKARD. Does the Stirling engine appear to have the ability to be produced at a cheaper cost than the standard engines now?

Mr. NIGHTINGALE. Yes. That was the——

Mr. PACKARD. Certainly it does operate more efficiently, but what about the initial cost.

Mr. NIGHTINGALE. Yes. That was one of the driving features behind our effort in going from the Mod I, which was the first engine in the program, to the Mod II. The Mod II, the primary goal was to make it manufacturable as well as maintain the high performance, and we were able to accomplish that.

We went to a separate manufacturing company in Detroit, Pioneer Engineering & Manufacturing, who did a manufacturing cost of the engine for us, independent, and compared it to what they knew on Stirling and diesel, and the initial manufacturing costs of the Mod II fell in between the cost of a spark-ignition and a diesel engine for passenger cars. We were rather pleased with that, and certainly with more development we could engineer more cost out of the design, certainly.

Mr. PACKARD. One last question, Mr. Chairman.

You mentioned that there are multitudes of different kinds of engines with research being done on them, Stirling being one. Do you see the Stirling engine, in comparison to these other types, emerging as perhaps one of the next generations of engines, or do you see something else that might be even more effective.

Mr. NIGHTINGALE. No, I see the Stirling as critical in the long-term future. I think that the fuel issue is going to come back to us as a Nation in the short-term future, and that the ability of the Stirling to handle alternative fuels and to provide low emissions will be a driving force for that scenario.

Mr. Packard. Thank you, Mr. Chairman.

Mr. Nelson. Mr. Boehlert.

Mr. Boehlert. Mr. Nightingale, am I correct? You said if you can recoup the proposed deferral for 1986 and get $8 million for 1987, a total of $12 million, that will complete your request of Uncle Sam for your basic program?

Mr. Nightingale. That's right, Mr. Boehlert.

Mr. Boehlert. And that will get you where you want to get and where we for the last several years have told you we want you to get, pretty much on schedule?

Mr. Nightingale. Yes; that's correct.

Mr. Boehlert. Second, you mentioned MITI has committed $50 million to the program in Japan. Is that correct? Did I hear you correctly?

Mr. Nightingale. Yes, yes; I believe it equates to about $50 million.

Mr. Boehlert. Depending on the value of the dollar. It has changed 20 times in the last 10 minutes.

How about Nissan and Toyota? Are they participating in that program or is that under the exclusive sponsorship of the Government?

Mr. Nightingale. Nissan and Toyota per se are not participating in that program. However, Aisin Seiki is a division of Toyota and they are participating; Aisin Seiki is participating in that program.

Mr. Boehlert. Financially?

Mr. Nightingale. Yes, yes. Yes, they are. Right. I'm not exactly sure of the arrangements. That's why Mr. Goldwater and I are going to Japan, to find out the details, but I believe that the salaries are covered by the companies and the hardware and so forth are paid for through the Government. It's basically what we would call a cost-sharing effort.

Mr. Boehlert. OK. Now the logical question that we as representatives of the people have to ask is, "What's in it for the Government?" Don't you have a payback provision in your contract?

Mr. Nightingale. Yes, we do.

Mr. Boehlert. What do we stand to gain in terms of——

Mr. Nightingale. $225 million.

Mr. Boehlert. Is that earmarked money? No, I was just kidding. [Laughter.]

But would you sort of explain that for me. I kind of like that idea.

Mr. Nightingale. Well, MTI was not in a position to cost-share. We are not big enough, and so in the provision of the contract we had a payback clause which was to the order of 2.25 times the amount of money, broadly speaking, invested into the ASE Program since 1978 is about $100 million, so that payback will equate to approximately $225 million to the Government.

Mr. Boehlert. We'll do pretty well, then, won't we, as a Government, two for one?

Mr. Nightingale. I think so, sir.

Mr. Boehlert. Gee, I wish we could do better with our other investments.

Mr. Nightingale. Well, we're trying hard to get Deere into line and some product users in line. I think it will pay off.

AVAILABLE

Mr. **Boehlert**. Would you speculate that because we've got a glut in the market, in the oil market—$15 a barrel—that may be one of the reasons why Detroit is not—"Detroit," I'm using that generically—is not as responsive as perhaps we all would like?

Mr. **Nightingale**. Yes. I think so, Mr. Boehlert. Now the driving force we felt was the mileage, the fuel economy, but of course when you compare what the companies have to invest in new tooling and manufacturing processes and things like that, where it could be $500 million or $1 billion—who knows—I can see where unless there is a strong economical driving force produced by an end user to begin with, that the manufacturer themselves are not going to step out and incorporate a new technology like this. I think if I was in their shoes as a business person, I would have a difficult time making that decision at this point in time.

Mr. **Boehlert**. So in summary is it fair for me to say that this multiyear program, involving an investment thus far on the part of Uncle Sam of close to $100 million, we are this far from the end where we all want to be, but if we don't go that last mile, that it might all be for naught? Is that fair to say? Not all for naught, but——

Mr. **Nightingale**. It won't be all for naught, certainly. You have engines, you have——

Mr. **Boehlert**. But there will be a lot of opportunities lost.

Mr. **Nightingale**. Definitely the spinoff programs and the interests of John Deere and MTI would dry up almost immediately. They are not funded sufficiently internally to support themselves. These are small spinoff programs, and I think we would lose a great deal in establishing the links that we have established. Over the past only a year, a year and a half, has this happened, have we been able to get in with a manufacturer and a product user, and we lose that. I think that is far more important than the fact that maybe we wouldn't complete the last test on the Mod II and be able to give you some final set of data to prove that it is, in fact, commerciable.

Mr. **Boehlert**. One last question, Mr. Chairman.

If we turn off the spigot now—and I want you to address the payback provision—does that mean we lose the potential of reaping a sizable dividend for the investment thus far? What happens if we say no this time around?

Mr. **Nightingale**. There is—again, it would depend on how we were stopped and how the program came to an end. In the case of a termination, in which there is no more money and the Government must terminate, under the termination clause there is no payback.

Mr. **Boehlert**. It looks like pretty good numbers to me. A modest investment gives some promise of bringing a pretty good return to the Government.

Thank you for your testimony, Mr. Nightingale.

Mr. Chairman, thank you.

Mr. **Nelson**. Anyone else for any questions?

Mr. **Lewis**. Mr. Chairman.

Mr. **Nelson**. Certainly.

Mr. **Lewis**. Mr. Nightingale, could you explain to us the payback of your contract? Do you have a payback in your contract with the Federal Government?

Mr. **Nightingale**. Yes, we do.

Mr. **Lewis**. Could you explain that a little better?

Mr. **Nightingale**. Yes; the payback clause is very specific, that after the closure of the program, in the case of commercialization of the product, that to the ratio of 2.25, of the engines that are manufactured and sold in the future there would be a payback to the Government of $2 to $2.25 hundred million, roughly.

Mr. **Lewis**. Thank you, Mr. Chairman.

Mr. **Nelson**. Mr. Packard.

Mr. **Packard**. One last question that I have, Mr. Chairman.

Mr. **Nelson**. Certainly.

Mr. **Packard**. In following up on Mr. Boehlert's questioning regarding the investment the Government has made into this particular project, we normally do not do a good job of converting a concept to a marketable product, comparatively speaking. In other countries we seem to be outmarketed in that area. This appears to be one that we are carrying to a product that can be marketed competitively.

What do you do when you look at projects at the early stages? Go back to the beginning of the Stirling engine. Were you at that time envisioning that you would get to the point where it would be a good investment in terms of a marketable product?

Mr. **Nightingale**. Yes, definitely, Mr. Packard. Yes. Back in 1978 we were certainly faced with some very, very difficult technical challenges. The criticism at that time was it was too heavy, it was too costly, it wouldn't apply to the automotive driving cycle, you couldn't respond to the transient nature. We all along felt that in the logic of the program, by coming in with the Mod I and working on it and then coming in with a second-generation engine as we did, called the Mod II, that we had a good chance of meeting those goals.

As I said in my written testimony, there still are some weaknesses. I won't try to imply anything otherwise. One weakness is a difficulty at low temperatures, minus 20 degrees Fahrenheit. That's a technology that we haven't had time or the funding to work on, but there are weaknesses. But as far as being commerciable, we feel that the Mod II has reached that point.

Mr. **Packard**. I just came from a hearing where we were evaluating many of our renewable fuel types of research projects—the photovoltaic, the coal gasification, and solar and geothermal and some of those. Most of those projects are not going to result in a commercially viable process, and will be primarily—the benefit of those is for basic research into those areas, but not to produce a marketable process or product. This one seems to be. Is that a factor, as you evaluate projects on new starts?

Mr. **Nightingale**. Yes, it is. And in the case of our charter here under the ASE, we always felt that in addition to the technical goals—the mileage, the emissions—that life and reliability, which are very key to commercializing, were as important factors as the performance itself, and we tried to couple the three throughout the process of the program.

I must say that you just reminded me of something. This basic technology, though, is applicable in other places that are not what you would define as commercial products. One is that a lot of our technology from this program is going into the SID Space Program. The Stirling engines, free piston Stirling engines, are being looked at as dynamic systems for Space Station and SDI applications, and we're talking about the same basic technology that has evolved out of the ASE Program, the same.

Mr. **Packard**. Thank you, Mr. Chairman.

I think that we are more and more going to have to look in terms of what kind of a return on our investment on research projects the Government can expect, as perhaps more of an important issue as to whether we go into a new project or not, a new start. I think this is an interesting illustration of the fact that we can identify, perhaps, projects that will show a return, in the space program particularly, I think, even though that may not be an immediate return, but certainly as the shuttle is now showing areas where it becomes a commercial vehicle as well as, of course, a research vehicle.

Thank you.

Mr. **Nelson**. Any other questions?

OK, Mr. Nightingale. Thank you very much, and Mr. Goldwater. We appreciate it very much.

Mr. **Nightingale**. Thank you, Mr. Chairman.

Mr. **Nelson**. I would like to welcome Mr. John Boppart and Mr. Harold Helms.

STATEMENT OF JOHN BOPPART, SENIOR VICE PRESIDENT, GARRETT TURBINE ENGINE CO., THE GARRETT CORP., ACCOMPANIED BY SERGE GRATCH, DIRECTOR, VEHICLE, POWER TRAIN AND COMPONENTS RESEARCH LABORATORY, FORD MOTOR CO.

Mr. **Boppart**. Mr. Chairman, I am John Boppart. I have asked to join me at the table, Serge Gratch, who is the director of Ford Motor Company's Vehicle, Power Train, and Components Research Laboratory.

Mr. **Nelson**. Pretty good. Please proceed.

Mr. **Boppart**. All right. My name is John Boppart. I am senior vice president of Garrett Turbine Engine Co. We are part of Allied Signal, which was formerly the Signal Companies of La Jolla, CA.

Garett and Ford Motor Co. are conducting the AGT101 Advanced Gas Turbine Program under contract to the Department of Energy and NASA. Garrett is the prime contractor, with major program support from Ford. Other major contractors in critical areas supporting us are shown here.

The purpose of this program is to develop high-risk and long-range technology for advanced automotive gas turbines for future automotive and other powerplant uses. The major emphasis has been the development of ceramic component technology for gas turbines and, as I will show you, the progress to date has been extremely encouraging.

Today I would like to focus on two issues: first, why this country needs the ceramics program, and particularly that which is being provided only by the AGT programs; and, second, why this program deserves continued Government support.

Why is ceramics important to us? There is a limited supply and a high cost associated with the strategic materials that are otherwise required to implement gas turbines and to bring their advantages to wide markets, such as automotive. By contrast, the materials that go into ceramics are widely available in this country and are of low cost, so ceramics is really the only technology which makes possible the application of the benefits of light weight, fuel efficiency, and the ability to handle a wide variety of fuels such as automobiles.

Now why is the AGT Program important? This program has been the major Government and industry-sponsored program which has been devoted to moving the focus of ceramics from the research laboratory to a practical application, such as an automotive gas turbine engine. The program has been the only one which has started from a base of designing an all-ceramic gas turbine engine, and the Garrett and Ford program has now progressed to testing of the all-ceramic engine which is illustrated here.

The program has truly been the focus of practical ceramics technology development in this country. It has taken ceramics, as indicated, from the research area to a focus on practical applications. It has permitted them to be tested and evaluated in real operating environments, and it has been the mechanism which has permitted U.S. industry to stay competitive with foreign ceramics technology. And I have to make the last statement with a certain amount of trepidation because we are not, in fact, doing a very good job in the basic ceramics industry of staying competitive with the very strong thrust that the Japanese are making in this direction.

In an international gas turbine conference in Japan there was shown this prototype vehicle, which is powered by a 100 horsepower ceramic gas turbine. As indicated by the caption, which says, "Ceramic Gas Turbine Engine—A Powerplant For For The Near Future," we think that is a very bold statement that the Japanese are making about a technology which we continue to regard as rather high-risk and long range. So, as you can see, the pressure is really on us.

What is the result of this pressure? We have tried to evaluate the impact of ceramics on the future U.S. economy, and we have shown here an analysis of the impact in outyears on the gross national product of two cases. The lower line represents what we think the impact will be if the Japanese come to dominate the application of ceramics to automotive gas turbines. The upper line shows the benefit that we believe would accrue from a successful U.S. dominance of that market and, as you can see, it makes a swing of tens of billions of dollars in the gross national product.

This also translates into effect on our employment, and again we think that there will be a swing of hundreds of thousands of jobs in American industry between the cases where the Japanese succeed in dominating this market and the case in which we succeed in dominating it.

The Japanese, as I said, are well on their way to implementing this. On the other hand, the AGT program is developing technology which is of great interest to us for Government as well as commercial applications. The technology and the component technology that we are developing in this program has direct application to a number of military applications, aircraft, solar power generator-sets, and industrial engines. A fallout in the near term is the application of ceramics to turbochargers for piston engines, and there will be a general fallout of enhancing of the introduction of a wide range of ceramic products into commercial application.

Where are we going in this program in 1986? As this chart indicates, we are in the last year of the Automotive Gas Turbine Program. We have gone through an active period of developing ceramic structures, ceramic components, and putting them together in a proof-of-concept power train development.

Looking at the very lowest line toward the right-hand side, there is a triple triangle that says, "all-ceramic engine at the end of fiscal 1985." We are now at that point. We are beginning to operate an all-ceramic engine and to develop the required technology. By the end of fiscal 1986, at which time this progarm ends, we hope to have demonstrated 100 shaft horsepower with a good fuel economy and low emissions in the test bed engine which is the focus of this program.

In this program the Garrett-Ford activity has led to the production of over 15,000 prototype ceramic parts, including the most difficult part for a ceramic engine, the ceramic gas turbine rotor down in the lower righthand corner, and all of these parts have now been brought together in an all-ceramic engine for testing.

Where should we go in the future? The Department of Energy, in cooperation with Oak Ridge National Laboratory, and NASA, has initiated a generic ceramic development program in 1984. It is also called the Ceramic Technology Project, or CTP, and the focus of this program is to develop the basic manufacturing technology for the ceramic raw materials which are needed to make the parts required for engines of our kind.

Picking up on that, the Department of Energy now has proposed a program called "Advanced Turbine Technology Applications Project," or ATTAP, which is to be a 5-year program beginning in fiscal 1987. Its purpose is to assess, in the real-world environment of a gas turbine test bed application, the ceramics that are being produced by the CTP. The plan of this program is to select from the basic technologies begin developed under CTP, promising ceramics technologies, develop them into AGT components, develop the processes for making them in a commercial way, and testing and validating this technology in the test rigs which exist as a result of the AGT program.

I would like to perhaps simplify and clarify the meaning of this program by a simple analogy. To me ATTAP, in its continuing technology development, is an exact analogy of the role that NASA played in the 1930's and 1940's in developing the basic aeronautical technology which provided the support for the current U.S. dominance of the world market in aeronautical products. The intention and the format of ATTAP is to precisely the same thing with regard to the application of ceramics to engine technology.

What if we don't go forward? If this program is not picked up on and ceramics technology not continued, inevitably the development of ceramics in this country will slow down. We believe that the foreign competition, which is very active, will bypass us. We will not only lose an economy and jobs, but a return of the fuel crisis would find us without a really viable alternative in terms of an engine well-adapted to automobiles, which has the capability of high fuel efficiency and of good alternate fuel capability.

Our recommendation is to continue this program, of course, to its completion; to continue the DOE and NASA ceramic technology projects, providing the basic research and ceramics technology; to initiate the ATTAP program in fiscal 1987; to continue to evaluate the ongoing generations of ceramics so as to maintain the significant lead which has been developed in this country as a result of the AGT programs.

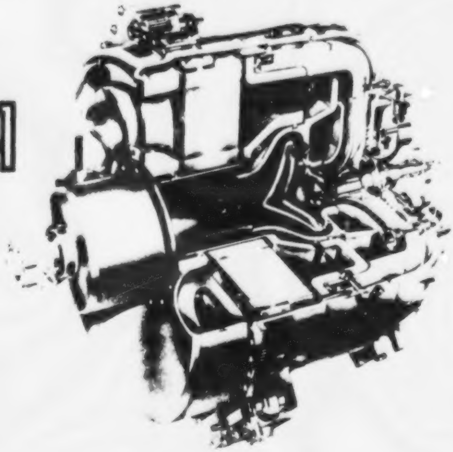
That's the conclusion of my summary. Thank you.

[The prepared statement of Mr. Boppart follows:]

TESTIMONY BEFORE
THE SUBCOMMITTEE ON TRANSPORTATION,
AVIATION AND MATERIALS
OF THE
COMMITTEE ON SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

PROGRESS REPORT GARRETT/FORD AUTOMOTIVE GAS TURBINE PROJECT

AGT101



27 FEBRUARY 1986

JOHN BOPPART
SENIOR VICE PRESIDENT
GARRETT TURBINE ENGINE COMPANY

GARRETT TURBINE ENGINE COMPANY
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

JOHN A. BOPPART

Senior Vice President

Education

B.S. in Mechanical Engineering, California Institute of Technology, 1952

M.S. in Mechanical Engineering, California Institute of Technology, 1953

Work History

1957 to Date: Garrett Turbine Engine Company

- Senior Vice President
- Vice President Engineering
- Director of Engineering
- Assistant Director of Engineering, Power Systems
- Assistant Director of Engineering, Pneumatic Systems
- Chief of Pneumatic Control Systems
- Senior Project Engineer, Pneumatic Actuation Systems
- Project Engineer, Pneumatic Control Systems
- Assistant Project Engineer, Advanced Power Generation Systems
- Senior Systems Engineer, Systems Support Group

1953 to 1957: AiResearch Manufacturing Company of Los Angeles

- Preliminary Design Engineer
- On loan to Advanced Design Group, NAP Project, Oak Ridge National Laboratory (1956)

Responsibility/Experience

Mr. Boppart has been Senior Vice President of Garrett Turbine Engine Company since August of 1985.

As Vice President of Engineering, Mr. Boppart was responsible for all engineering activities for Garrett Turbine Engine Company.

As Assistant Director of Engineering, Mr. Boppart was responsible for all engineering activities associated with all AiResearch Power Systems products. Prior to this he was similarly responsible for all AiResearch Pneumatic Systems products.

All engineering functions involving the Power Systems and Pneumatic Systems product lines were under his direction including engineering estimates through design, development, and qualification, and the production liaison activities during the follow-on production deliveries.

Mr. Boppart's prior experience also includes work in various capacities of engineering on pneumatic valves and controls, air motor pneumatic actuation systems, missile and space control valves, space power systems, gas turbine auxiliary power systems, and aerospace environmental control systems.

PS-362:0215

GARRETT TURBINE ENGINE COMPANY
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

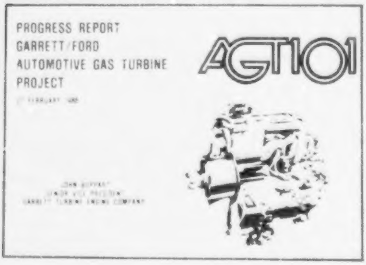
Mr. Chairman and Members of the Subcommittee:

My name is John Boppart (Figure 1). I am Senior Vice President for Garrett Turbine Engine Company, a Division of The Garrett Corporation (an Allied-Signal Company).

Garrett and Ford Motor Company are working together on the Advanced Gas Turbine (AGT101) Program under contract to the Department of Energy and NASA (Figure 2). Garrett is the prime contractor, with major support from Ford. Other major subcontractors supporting us in this program are Carborundum Company, Corning Glass Company, and AiResearch Casting Company (another division of Garrett).

The AGT101 team has been developing high-risk long-range technology for advanced automotive gas turbines for future automotive and other power plant uses. Major emphasis of the program has been to develop ceramic component technology for gas turbine engines.

In today's testimony, I wish to focus on why this country needs the ceramics technology that is being provided only by the AGT program (Figure 3) and why ceramics needs continued U.S. Government effort.



PROGRESS REPORT
GARRETT/FORD
AUTOMOTIVE GAS TURBINE
PROJECT

AGT101

Figure 1. Testimony Before the Subcomittee on Transportation, Aviation, and Materials.

I. WHAT IS CERAMICS?

- o Ceramics is a science related to nonmetallic and inorganic materials.
  - o Silicon, nitrogen, and carbon are elemental constituents (i.e., sand).

II. WHY IS CERAMICS IMPORTANT?

- o Elemental constituents are readily available in the U.S. in an inexhaustible supply.
- o The need for strategic materials[1] is reduced (many heat engines, including gas turbines, employ strategic materials).

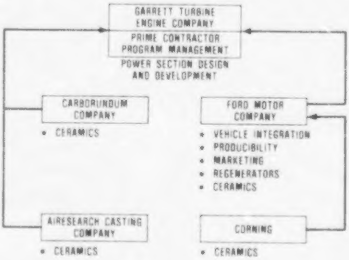

GARRETT TURBINE ENGINE COMPANY
PRIME CONTRACTOR
PROGRAM MANAGEMENT
POWER SECTION DESIGN AND DEVELOPMENT
CARBORUNDUM COMPANY
• CERAMICS
FORD MOTOR COMPANY
• VEHICLE INTEGRATION
• PRODUCIBILITY
• MARKETING
• REGENERATORS
• CERAMICS
AIRESEARCH CASTING COMPANY
• CERAMICS
CORNING
• CERAMICS

Figure 2. Garrett/Ford AGT101 Program Team.

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[1] "A strategic material is one for which the quantity required for essential civilian military uses exceeds the reasonably secure domestic and foreign supplies, and for which acceptable substitutes are not available within a reasonable period of time." Office of Technology Assessment, Strategic Materials: Technology to Reduce U.S. Import Vulnerability (January 1985), p. 13.

U.S. NEEDS CERAMICS TECHNOLOGY
THAT HAS BEEN PROVIDED BY THE
AGT PROGRAM AND REQUIRES CONTINUATION

Figure 3. Today's Focus

  - Dependence on unreliable foreign sources[2] is reduced, providing protection of National Security.
  - There are not enough strategic materials in the world for automotive gas turbine production.
  - Cost of strategic materials for an automotive gas turbine is prohibitive.

o Ceramics[3] offers the automotive gas turbine:

  - Capability to operate at higher temperatures without cooling, thus providing higher efficiency
  - Better fuel economy
  - Substantially lower cost potential
  - Adequate raw material for mass production
  - Lower friction (tribology)
  - Lower weight

- MATERIALS AVAILABLE IN U.S. IN INEXHAUSTIBLE SUPPLY
- NEED FOR STRATEGIC MATERIALS REDUCED
- CERAMICS FOR AUTOMOTIVE GAS TURBINE ARE ESSENTIAL
  - COST
  - HIGHER EFFICIENCY — BETTER FUEL CONSUMPTION
  - ADEQUATE RAW MATERIAL FOR MASS PRODUCTION

Figure 4. The Importance of Ceramics.

  - Lower inertia of rotating parts (less energy) (Figure 4)

III. WHERE ARE WE IN CERAMICS TECHNOLOGY DEVELOPMENT?

o The AGT101 program has processed over 15,000 first-generation ceramic parts for evaluation.

o Limited component and engine testing has been conducted under actual operating environment conditions.

o Ceramics is at the stage of development that metallurgy was 30 years ago (Figure 5).

IV. WHY IS THE AGT PROGRAM IMPORTANT?

o The AGT program has been the major U.S. Government/industry-sponsored program

- AGT101 HAS PROCESSED OVER 15,000 FIRST GENERATION CERAMICS PARTS
- LIMITED TESTING UNDER ACTUAL OPERATING ENVIRONMENT
- CERAMICS ARE 30 YEARS BEHIND METALS DEVELOPMENT

Figure 5. Ceramics Technology Development Status.

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[2] "Three nations, South Africa, Zaire, and the U.S.S.R., account for over half of the world's production of chromium, cobalt, manganese, and platinum group metals." Ibid., p. 7.

[3] "Ceramics, composites, and unconventional metallic materials have properties that suggest they might serve as substitutes for conventional materials that require strategic metals." Ibid., p. 52.

devoted to moving the focus of ceramics from the research laboratories to a practical application -- an automotive gas turbine engine.

- The program has been the only one in the U.S. that has allowed an all ceramic engine hot section to be designed from inception (Figure 6).
- The program has allowed ceramics expertise from the auto industry, the gas turbine industry, the ceramics industry, and the government to be combined to develop ceramics technology and integrate this technology into the gas turbine operating environment via test rigs and engine test beds -- the only practical approach to ceramics technology development.
- The program has allowed the team to advance this long-range, high-risk technology, which no individual company could afford.
- The program has allowed the time and resources required for an iterative give-and-take ceramics design and development effort.

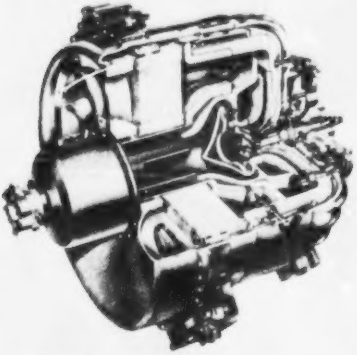

Figure 6. AGT101 Power Section.

- The program has allowed the fabrication of test rigs and engine test beds for extensive ceramics development and evaluation.
- Without the AGT program, ceramics development would take much longer and cost much more.
- The program has allowed the U.S. industry to stay competitive with, and perhaps ahead of, foreign ceramics technology development of high technology materials.
- The AGT101 gas turbine operates without oil in the hot section -- an air bearing is utilized -- thereby offering less friction (tribology) and lower energy consumption to the future automotive driving public (Figure 7).

V. WHAT DOES THE CERAMIC GAS TURBINE OFFER THE AUTO INDUSTRY?

- The auto industry must supply high quality products in cost-effective quantities to meet customer requirements. Providing the technology embodied in the AGT101 can be developed to meet these demands,

- FOCUS OF CERAMICS TECHNOLOGY DEVELOPMENT IN U.S.
- CERAMICS BEING DEVELOPED BY INDUSTRY AND GOVERNMENT EXPERTISE IN THE MOST EXPEDITIOUS AND PRACTICAL WAY
- CERAMICS TESTED AND EVALUATED IN ACTUAL OPERATING ENVIRONMENT
- ONLY PROGRAM THAT HAS ALLOWED DESIGN OF CERAMIC GAS TURBINE FROM INCEPTION
- HAS ALLOWED U.S. INDUSTRY TO STAY COMPETITIVE WITH FOREIGN CERAMICS TECHNOLOGY DEVELOPMENT

Figure 7. The Importance of the AGT Program.

the automotive gas turbine would provide several attractive features, as below.

- Small-car fuel consumption in full-size cars and light trucks.

- The lightweight rotary power unit uses continuous combustion. This combination ensures smooth operation and low noise. Vehicle acceleration and top speed are more than adequate when advanced transmissions are used.

- The continuous combustion process has the additional benefit that it can be developed for excellent long-term pollution control.

- The multi-fuel capability of the gas turbine ensures that it is not solely dependent on petroleum-based fuels. Alternative fuels derived from nonpetroleum sources can be burned efficiently and cleanly in the engine. This particular feature is highly relevant to the longer term, when the present availability of conventional fuel, both domestic and imported, could be constrained for many reasons.

o A number of engine concepts using advanced thermodynamics (adiabatic diesels, turbocompound engines, bottoming cycles) is under investigation in the quest for ultimate fuel economy. The automotive gas turbine is a viable contender in this continuing research endeavor around the world.

o The United States auto industry is facing persistent competition from overseas. Our competitors are well aware of the potential of the ceramic gas turbine. Active joint industry, university, and government programs are underway in Japan, the United Kingdom, and Germany. A display at the International Gas Turbine Conference in 1984 in Japan showed a Japanese prototype vehicle, with the caption "Ceramic Gas Turbine Engine -- a powerplant for the near future," a significant statement for technology we still consider long range and high risk (Figures 8 and 9). The Japanese threat should be taken very seriously. The Japanese ceramic effort is accelerating dramatically in comparison with other countries including the U.S. (Figure 10)[4]. As you can see (Figure 11)[5], if the Japanese dominate the ceramic automotive market, the U.S. Gross National Product will be adversely affected in the mid-1990s. On the other hand, if the U.S. dominates the market, the Gross National Product will be significantly enhanced. A similar impact will take place in U.S. employment as shown in Figure 12 [5]. The Japanese are well on their way to such a dominating ceramic position, as reflected by the Nissan announcement last fall that they are producing 500 cars a month utilizing ceramic turbocharger wheels for the Japanese market.

o The automotive gas turbine is not possible without the ceramics technology under development in the AGT program (Figure 13).

VI. ARE OTHER GOVERNMENT AGENCIES AND INDUSTRY INTERESTED?

o All the military services have expressed interest in ceramic gas turbines. The AGT program has served as the focus for U.S. Government interest in ceramics. The services wish to take advantage of the work sponsored by the AGT program. This work should continue.

o The aircraft industry is interested in gas turbines that are more efficient, lighter

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[4] L.R. Johnson, A.P.S. Teotia, and L.G. Hill. "A Structural Ceramics Research Program: A Preliminary Economic Analysis," Argonne National Lab ANL/CNSU-38, March, 1983.

[5] Arvind P.S. Teotia, and Larry R. Johnson. "Macroeconomic Effects of U.S. or Japanese Dominance in Structural Ceramic Technology for Heat Engines," Argonne National Lab, Argonne, IL, September 1985.

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- JAPANESE PROTOTYPE CAR
  - REAR MOUNTED DUAL-AXIS 100 HP CERAMIC GAS TURBINE
    - OPERATING TEMPERATURE 2462F
    - CERAMIC COMPONENTS
      - TURBINE BLADES
      - TURBINE SHROUD
      - COMBUSTION CHAMBER LINES
      - HEAT EXCHANGER CORE

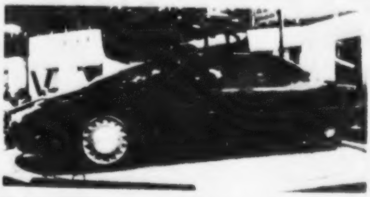

Figure 8. Foreign Ceramics Competition is Developing.

セラミックガスタービン

Figure 9. Japanese Gas Turbine Engine.

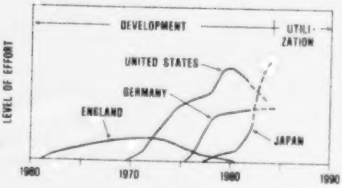

Figure 10. Japanese Ceramic Effort Timed to Build on Worldwide Base.

weight, and less expensive. The use of ceramics offers these potential gains.

- o The AGT101 is a strong candidate for a solar generator set currently being considered for long-range development by the DOE.
- o A ceramic AGT101 derivative has been studied by NASA for aircraft propulsion application.
- o Industrial gas turbines are candidates for ceramics.
- o U.S. industry is evaluating ceramic turbocharger turbine wheels for automotive application.
- o Ceramic components are beginning to be employed by industry for a wide range of production applications (Figure 14).

VII. WHERE ARE WE GOING IN FY86?

- o The objective of the FY86 AGT effort (Figure 15) is to demonstrate the proof of concept of an automotive gas turbine engine with all ceramic hot flow path components, both stationary and rotating, with the potential for:
  - Operating temperature to 2500F uncooled

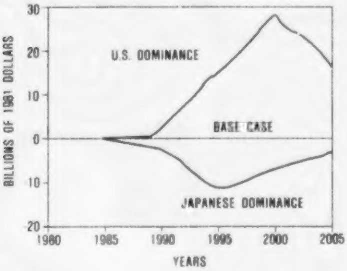

Figure 11. Japanese Dominance of Ceramic Automotive Market Affects U.S. Gross National Product.

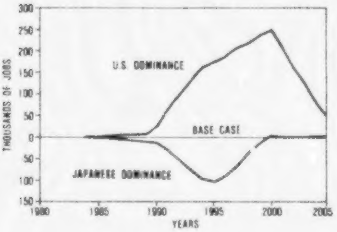

Figure 12. U.S. Employment will be Affected by Japanese Dominance of Ceramic Automotive Market.

- Meeting environmental standards
- Operating on a wide range of fuels
- Achieving 42-43 MPG (CFDC) when installed in a 3000 pound vehicle

o The AGT101 Program is to be completed at the end of 1986 (Figure 16).

o Ceramic parts have been, and are continuing to be, tested under simulated engine operating conditions, individually and

- AGT TECHNOLOGY, COUPLED WITH HIGH QUALITY PRODUCTION IN COST EFFECTIVE VOLUMES, COULD PROVIDE
  - SMALL-CAR FUEL CONSUMPTION IN FULL-SIZE CARS AND LIGHT TRUCKS
  - SMOOTH OPERATION, LOW NOISE, AND GOOD "ON THE ROAD" PERFORMANCE
  - LONG-TERM POLLUTION CONTROL CAPABILITY
  - ABILITY TO BURN CONVENTIONAL AND ALTERNATIVE (NON-PETROLEUM) FUELS
- FOREIGN COMPETITION IS PURSUING CERAMICS TECHNOLOGY
- THE AUTOMOTIVE GAS TURBINE IS NOT VIABLE WITHOUT CERAMICS

Figure 13. The Auto Industry Needs Ceramics Technology.

- AGT PROGRAM SERVES AS FOCUS FOR GOVERNMENT INTEREST IN CERAMICS
- OTHER APPLICATIONS
  - CERAMIC GAS TURBINES FOR AIRCRAFT, SOLAR GENERATOR SETS, INDUSTRIAL ENGINES
  - TURBOCHARGER TURBINE WHEELS
  - WIDE RANGE OF CERAMIC PRODUCTS BEING INTRODUCED INTO PRODUCTION

Figure 14. Interest of Government Agencies and Industry Served by AGT Program.

- DEMONSTRATED PROOF OF CONCEPT OF AUTOMOTIVE GAS TURBINE ENGINE WITH ALL CERAMIC HOT FLOWPATH COMPONENTS WITH POTENTIAL FOR
  - OPERATING TEMPERATURE TO 2500F UNCOOLED
  - MEETING ENVIRONMENTAL STANDARDS
  - OPERATING ON A WIDE RANGE OF FUELS
  - ACHIEVING 42-43 MPG (CFDC) WHEN INSTALLED IN A 3000 POUND VEHICLE

Figure 15. AGT101 FY86 Program Objectives.

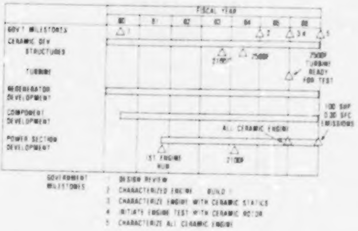

Figure 16. AGT101 Program Schedule.

then as subassemblies, to qualify them for engine test evaluation. A limited number (500+) of the parts has passed these screening tests, but many more must pass.

- Ceramic component rig testing to 2500F continues. (The AGT101 operates at 2500F to obtain optimum fuel economy.) Much more test experience at these high temperatures is required to resolve problems and guide materials development before successful engine test bed operation can be assured.

- Ceramic subassemblies have been tested in the engine test bed for over 100 hours at 2100F. Ceramic subassemblies will continue to be rig tested to qualify them for 2500F all-ceramic engine testing.

- The gas bearing (which operates without oil) in the hot section of the engine has been developed to a high level of performance and will be tested in the 2500F engine test bed.

- The ceramic turbine rotor development was considered the most challenging job when the AGT101 program was initiated. It has taken six years to develop the turbine wheel to the point at which it can be successfully cold spin tested to 115,000 rpm as a proof test. Rotors also have been hot tested in a rig and in an engine test bed to 1850F. Ceramic turbine rotors will continue to be developed for testing in the engine test beds to 2500F.

- The all ceramic engine (including turbine) testing has been initiated. By the end of 1986, the all-ceramic engine will be tested for:
  - 100 hours at temperatures to 2200F on an engine dynamometer
  - Short time operation at peak material limiting temperatures

- The proof-of-concept of the ceramic gas turbine will have been verified (Figures 17 and 18).

VIII. WHERE DO WE GO IN THE FUTURE?

- DOE-ORNL and NASA have initiated generic ceramics programs (Ceramic Technology for Advanced Heat Engines Program). This program is organized to assure that complimentary efforts of universities, industry, and the Government provide new, tougher, more reliable, and easier-to-produce ceramics or derivatives (Figure 19).

- The AGT101 is expected to successfully demonstrate proof of concept using high technology materials this year. We know that questions relating to second-generation materials, reliability, supply infrastructure, the demands for high quality components produced in cost effective quantities, and others remain unanswered.

- The value of using realistic operating hardware when attempting to answer these questions is beyond doubt. The AGT programs offer already-paid-for test rigs and engine tests beds for developing and evaluating the next generation of ceramics, once the parts are fabricated.

PS-362:0218

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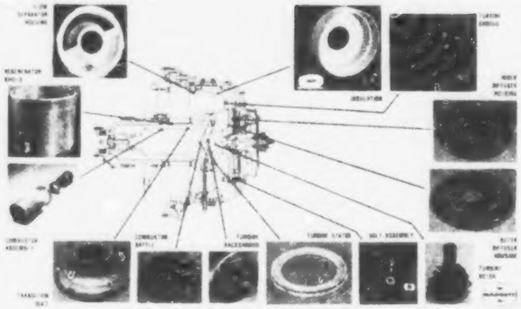

FLOW SEPARATOR HOUSING
REGENERATOR SHIELD
INSULATION
TURBINE SHROUD
INNER DIFFUSER HOUSING
COMBUSTOR ASSEMBLY
TRANSITION DUCT
COMBUSTOR BAFFLE
TURBINE BACKSHROUD
TURBINE STATOR
BOLT ASSEMBLY
OUTER DIFFUSER HOUSING
TURBINE ROTOR

Figure 17. AGT101 Ceramic Components.

- CERAMIC PARTS MOVING FROM INDIVIDUAL AND SUBASSEMBLY SIMULATED OPERATING TESTING TO ACTUAL ENGINE TEST BED OPERATION
- ALL CERAMIC ENGINE TO BE TEST EVALUATED IN FY86 ON A DYNAMOMETER
  - 100 HOURS TO 2200F
  - SHORT TIME OPERATION AT PEAK MATERIAL LIMITING TEMPERATURES

Figure 18. AGT101 Development Direction.

- DOE-ORNL-NASA INITIATED CERAMIC TECHNOLOGY FOR ADVANCED HEAT ENGINE PROGRAM IN 1984
  - ALSO CALLED CERAMIC TECHNOLOGY PROJECT
- DEVELOPING TECHNOLOGY BASE IN STRUCTURAL CERAMICS, CERAMIC COMPOSITES AND COATINGS CAPABLE OF PROVIDING RELIABLE AND COST EFFECTIVE COMPONENTS

Figure 19. DOE-ORNL-NASA Sponsoring Technology Research for Next Generation Ceramics.

The Aerospace Corporation conducted a survey for the DOE Technology Development and Analysis Division and reported in October 1984. Eleven engine/vehicle manufacturers, five petroleum refiners, and five universities and research institutes were surveyed. The following quotation was taken from Page 5A:

> The position of automotive and fuel experts regarding the use of the [illegible]T100 and 101 proof-of-concept engines as test beds for further development of ceramic components generally is very favorable, as is their position regarding DOE support of R&D for gas turbines in the heavy duty transportation sectors. Those in favor of the first activity (86 percent) see AGTs as having potential because of their multifuel capability, low emissions, and competitive fuel economy. They emphasize that only in an actual engine environment can engine components be subjected to the combined thermal and speed related stresses, and the interactions with other components that are required to evaluate new materials.

o DOE has evolved a program to continue the ceramic technology effort initiated in the

AGT and Ceramic Technology Project programs such that the United States will not lag behind world competition. The program is called Advanced Turbine Technology Applications Project (ATTAP). The objective of the ATTAP is to continue to advance the technological readiness of the automotive ceramic gas turbine engine through the development of processes to fabricate and test components from the improved (next generation) ceramic materials, expand ceramic properties experimental data base, expand analytical tools needed to support the ceramic industry, evaluate the reliability and durability of the next generation of high temperature ceramics, and assess low cost ceramic processing and manufacturing technology (Figure 20).

o The ATTAP is envisioned to be a 5-year program beginning in FY87. An ATTAP program plan is under development by DOE with inputs from industry (including Garrett and Ford), Oak Ridge National Laboratory, and NASA. Figure 21 shows the technology areas to be considered in the plan. The initial part of the program will involve assessment of the DOE-ORNL-NASA Ceramic Technology Project to determine which materials are best suited for evaluation in ATTAP. In addition, other non-government sponsored ceramic developed materials will be evaluated against the high temperature gas turbine requirements. Process development will then be initiated on the selected improved materials to fabricate test components for the AGT test beds.

- DEVELOP PROCESSES TO FABRICATE TEST HARDWARE FROM THE IMPROVED CERAMIC MATERIALS
- EXPAND CERAMIC PROPERTIES EXPERIMENTAL DATA BASE
- EXPAND ANALYTICAL TOOLS NEEDED BY CERAMIC INDUSTRY
- ASSESS LOW COST CERAMIC PROCESSING AND MANUFACTURING TECHNOLOGY
- EVALUATE RELIABILITY AND DURABILITY OF NEXT GENERATION CERAMICS

Figure 20. ATTAP to Cotinue U.S. Ceramics Technology Development.

- 5 YEAR PROGRAM BEGINNING IN FY87
- ASSESS NEXT GENERATION CERAMICS FROM NASA, ORNL, DOE AND INDUSTRY
- SELECTED CERAMICS TO BE FABRICATED INTO AGT COMPONENTS
- DEVELOP SEMI-AUTOMATED PROCESSES/MANUFACTURING TECHNOLOGY TO PROJECT CAPABILITY IN AUTOMOTIVE QUANTITIES
  - PRODUCTION METHODOLOGY
  - LOW COST POTENTIAL
- COMPONENTS TESTED IN EXISTING AGT TEST RIGS AND TEST ENGINES (ACTUAL OPERATING ENVIRONMENT)
- ACCELERATED AUTOMOTIVE DURABILITY TESTING
- PUBLISH DESIGN MANUAL TO DISSEMINATE TECHNOLOGY GAINED IN AGT AND ATTAP PROGRAMS

Figure 21. ATTAP Will Use AGT Test Beds to Develop Next Generation Ceramics.

o A more complete materials property data base will be generated to support the analytical design effort. The analytical design tools include thermal and stress analysis to calculate reliability under engine operating conditions. Verification test data is required to support this analysis. In addition, models are needed to define time-dependent failure modes such as creep and stress rupture. The development and adaption of uniform design practices is required to advance ceramic technology and assure reliability.

o A few selected component shapes, such as the ceramic turbine rotor, will be utilized to assess low cost processing and manufacturing technology. Several hundred components will be processed using equipment more automated than the current laboratory type so this technology can be extrapolated to automotive quantities to project yield and low cost potential. The question of low cost manufacturing capability is key to future of ceramics in the automotive gas turbine.

- A design manual will be prepared for government and industry use. The ceramic technology knowledge gained during the AGT and ATTAP programs will be summarized in the design manual.
- The ATTAP will culminate in the successful durability test of the improved ceramics in the engine test beds.

IX. WHAT IS AHEAD IN FY87?

- In FY87, progress in several areas should be accomplished in the ATTAP program (Figure 22). The DOE-ORNL-NASA ceramic technology projects as well as other industry-funded technology will be reviewed to select candidate ceramic materials. The remaining materials property data necessary for initial design will be attained via testing of these improved ceramics. Component design and analysis will be initiated. Fabrication development will be started for test components from the improved materials.
- Effort to assess low cost processing and manufacturing technology will begin during this period. Two or three materials and processes for study will be selected. Procurement of semi-automated process equipment will be started.
- Process development to extrude a high performance regenerator will be initiated.

- SELECT CANDIDATE MATERIALS FROM DOE ORNL NASA CERAMIC TECHNOLOGY PROJECTS AND INDUSTRY FUNDED ACTIVITIES
- BEGIN COMPONENT DESIGN AND ANALYSIS OF THESE IMPROVED MATERIALS
- TEST MATERIALS TO OBTAIN PROPERTY DATA
- BEGIN FABRICATION OF TEST COMPONENTS FROM IMPROVED CERAMIC MATERIALS
- BEGIN LOW COST PROCESSING AND MANUFACTURING TECHNOLOGY STUDY
- INITIATE DEVELOPMENT OF A HIGH PERFORMANCE REGENERATOR
- CONDUCT ENGINE DURABILITY TEST ON BEST AGT CERAMIC MATERIALS

Figure 22. ATTAP Progress Planned in FY87.

Additionally, technology to operate the core directly against the adjacent housing will be investigated to reduce leakage and increase performance. This technology is important for future regenerated ceramic engines.

- Engine durability testing of the best ceramic materials received during the AGT project will be conducted in FY87. This data will form a baseline with which to compare the improved materials.

X. WHAT IF WE DON'T GO FORWARD?

- Ceramics development in this country will slow dramatically. Since the technology is still considered long range and high risk, U.S. industry will devote limited resources to bring ceramics to production status.
- Foreign competition will bypass U.S. industry and offer ceramics for many applications before our industry does. Ceramics development is a national goal in Japan. Universities, industry, and the government seem to have a well-organized effort.
- The world oil supply is limited. Even without a return of the fuel crisis, U.S. industry will be ill-prepared without alternative, fuel efficient, and multi-fuel-burning power plants (Figure 23).

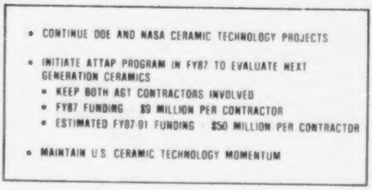
XI. WHAT DO WE RECOMMEND?

- Continue funding DOE and NASA ceramic technology projects.

- U.S. CERAMICS DEVELOPMENT WILL SLOW
- FOREIGN COMPETITION WILL BYPASS U.S. CERAMICS TECHNOLOGY
- RETURN OF FUEL CRISIS WOULD FIND U.S. AUTO INDUSTRY WITHOUT ALTERNATIVE FUEL EFFICIENT AND MULTI-FUEL BURNING POWER PLANTS

Figure 23. Lack of Future Development Would Prove Detrimental.

- o Initiate ATTAP program in FY87 to evaluate the next generation of ceramics.
- o Keep both AGT contractors involved.
  - Fund $9 million per contractor in FY87
  - Estimated total ATTAP funding $50 million per contractor (5 years)
- o Maintain U.S. ceramic technology momentum (Figure 24).



- CONTINUE DOE AND NASA CERAMIC TECHNOLOGY PROJECTS
- INITIATE ATTAP PROGRAM IN FY87 TO EVALUATE NEXT GENERATION CERAMICS
  - KEEP BOTH AGT CONTRACTORS INVOLVED
  - FY87 FUNDING — $9 MILLION PER CONTRACTOR
  - ESTIMATED FY87-91 FUNDING — $50 MILLION PER CONTRACTOR
- MAINTAIN U.S. CERAMIC TECHNOLOGY MOMENTUM

Figure 24. Recommendations.

Mr. LEWIS (acting chairman). Thank you, Mr. Boppart.

A question I asked earlier——

Mr. BOPPART. Mr. Chairman, I wonder if you would like to have Mr. Helms cover his project at the same time, so we could answer questions together?

Mr. LEWIS. Certainly. Go ahead. Why don't we do that?

STATEMENT OF HAROLD E. HELMS, CHIEF PROJECT ENGINEER, ALLISON GAS TURBINE DIVISION, POWER PRODUCTS GROUP, GENERAL MOTORS CORP.

Mr. HELMS. Thank you very much, Mr. Chairman.

I would like to wholeheartedly compliment Mr. Boppart on his testimony—a good summary of our programs.

We at General Motors have also had an automotive gas turbine program which has gone in parallel with the Garrett activity but hopefully which has not duplicated effort, but has had complementary effort. Again, as you will see, we have attempted to develop and engine which we call now a "proof of concept" engine. We feel this type of engine is absolutely necessary to prove the technology readiness, and especially in this critical ceramics area.

Our engine, too, has the potential for this 42.5 miles per gallon in a 3,000-pound vehicle, and we have worked very closely with the Pontiac people to make sure we address the three critical factors that you must have to have a product. Those three factors are cost, performance, and reliability.

The kind of automobile we have looked at is not only this one—the Citation 4, an advanced design vehicle for GM—but we have also tried to maintain applicability of this engine to automobiles such as our A-6000 and the Fiero automobile which we now market.

Next chart, please.

This is a picture of the engine on the test stand, and we too have now achieved many hundreds of hours of operating time, and we have tested ceramic components both as an individual component and we are now also assembling parts together to address running this whole engine with ceramic components by the end of this year.

Again I would point out that we have attempted to pursue ceramic components from many people. I apologize for that slide but if you read it accurately, you would find 14 different ceramic suppliers where we have spent money from the current program in an attempt to develop ceramics expertise in this country, but as well to evaluate ceramics expertise both in Germany and Japan. You might read Kyocera, Asahi Glass, the SEP is a French company, and the Feld Muehle Co. is a German company, where we have pursued vigorously the ceramic technology wherever we can find it.

Now I show this chart because I would like to call to your attention that when both Garrett and Allison started in 1979, we were told pieces—especially the kind of pieces you see on the right had of that chart—were impossible to make. We are now making those pieces. Where we are falling short is with the toughness of these materials in the particular environment that we have in the gas turbine engine, and we are falling short relative to yield and cost of components.

AVAILABLE

The next chart, please.

I show this picture because this is the first successful test of a gas turbine rotor in our engine, and it is a silicon nitride rotor made in Japan.

The next chart, please.

As we have addressed the monolithic ceramic picture, we find lack of toughness to be a problem, so we have also been addressing the composite ceramics in our program. A backplate for our hot turbine section is shown here, and this had been made for us by the Corning Glass people. This is a French manufactured combustion liner. It is a silicon carbide fiber, embedded in a silicon carbide matrix.

Next chart, please.

Here we show stationary parts, including the composite inner backplate in the lower right part of that picture made for us—the rest of the parts were made for us by Carborundum.

The next chart, please.

These are Carborundum-manufactured silicon carbide rotors, and this year we have tried to evaluate these rotors in our engine, and we continue to try to evaluate the Carborundum roters as well as the Japanese rotors.

The next chart.

I like to show this chart because one of the technical discipline areas that we face with ceramics is the very difficult area of defects and flaws in these materials. When we started our program we could find flaws that were fairly large, maybe 300 to 500 microns. Today we are now finding flaws such as this in our ceramics, and one of our dilemmmas is to know how to interpret the damaging effect of these flaws, and truly we have only begun to write the book on knowledge of what constitutes a critical flaw—a flaw that will cause failure—and a flaw that will not cause failure in an engine application.

Next chart, please.

Now I show this chart because of the issues, I think, that is before us all is the critically of fuels and the ability of different kinds of powerplants to operate on different kinds of fuels. I have attempted to show here the emission characteristics of our AGT 100. You should note with interest that we have tested with diesel and jet fuels, and now this year we have tested with methanol. In a separate program sponsored by General Motors, we have now tested with coal, dry micronized, powdered coal, also in a gas turbine.

You will note that the white box defines current emission standards. I note with a great deal of interest that the methanol is an extremely clean-burning fuel as compared to the diesel and jet fuels. I think the other thing of importance is that on the right, where it says, "diffusion flame combustors," that area is representative of typical turbojet type engines that are used today, and in fact we have developed now this premixed, prevaporized AGT 100 type combustor which yields these levels of emissions, and I think that's a very important development in our program.

Now we have shown again a schedule much like the one Mr. Boppart showed, and we too are approaching the end of our program, not having met all the goals that we had hoped for but again with some significant achievement. We identify again on the lower right hand the word "ATTAP" on that chart, and if I may say, sir, I would like to read to you my testimony from here on because I think it's that important.

The current U.S. Government-sponsored AGT Program and earlier U.S. Government-sponsored programs such as CATE have provided a large catalytic momentum to develop ceramic components, not only in America but also in such competitive overseas countries such as Japan, Germany, Sweden, and England, among others. The emphasis placed on ceramics, especially in Japan, has produced a real challenge to the United States to keep our lead in structural ceramics for heat engines.

Japanese ceramic effort encompasses large efforts by industry, government, and academic in Japan. Their current capabilities in ceramic component manufacturing may be superior to the U.S effort. The Japanese dedication to achieving superiority in structural ceramic parts, such as they now possess in electronic ceramic manufacturing, is verified by many United States Government, United States industry, and United States academic visitors to Japan. Also, the current AGT teams are now evaluating Japanese as well as American-made ceramic turbine components, with initial results favoring the Japanese components.

The ceramic effort in the United States is likely to slow significantly if Federal Government support for ceramic component development is withdrawn or substantially reduced. Such a reduction may reinforce the commitment by overseas ceramics developers to the degree that the U.S. could eventually become heavily dependent on foreign sources for these components, as has occurred, for example, in the case of electronic componentry.

In order to minimize such a risk, it is strongly recommended that that ATTAP Program be continued for at least 5 years and that Federal support be provided at a level that will assure continued progress through the full use of existing manpower, facilities, and equipment. We recognize the need to reduce the Federal deficit, but we are confident that a propoer balance can be achieved in helping to meet the objective as well as our goal of worldwide supremacy in ceramic technology.

Now in the balance of my testimony I have identified the technical challenges in what we call the ATTAP Program. We feel very strongly that there is a second and a third generation of ceramic components that will be forthcoming. Much of the basis has been laid with current programs, but the opportunities ahead of us in composites and other new ceramic technologies make it imperative, I believe, that we continue these kinds of projects. You can read at your leisure the recommended technical challenges in the ATTAP Program.

Gentlemen and ladies, I would like to thank you for the opportunity to testify before you this morning.

[The prepared statement of Mr. Helms follows:]

Testimony to the
House Subcommittee on Transportation,
Aviation and Materials
of the
Committee on Science and Technology
U.S. House of Representatives

27 February 1986

AGT 100

Department of Energy
Advanced Gas Turbine Technology Contract

Harold E. Helms
Chief Project Engineer—Allison Gas Turbine Division
Power Products Group—General Motors Corporation

HAROLD E. HELMS
Chief Project Engineer — Vehicular Turbines

Education

B.S. in Engineering Mechanics, Purdue University, 1948
M.S. in Engineering Mechanics, Purdue University, 1950

Work History

1952 to Date: Allison Gas Turbine Division
Power Products Group
General Motors Corporation, P.O. Box 420
Indianapolis, Indiana 46206

- Chief Project Engineer, Advanced Vehicular Engines
- Chief — Regenerator Systems
- Program Manager — NASA QCSEE Program
- Chief — Analytical Mechanics
- Section Head — Stress, Heat Transfer, Vibrations, Weights, and Computers
- Supervisor — Rocket Nozzles and Cases
- Deputy Leader — Allison Rolls Royce Joint Project
- Senior Project Engineer — T40 Engines, T56 Engines

1950 to 1952: Engineer, Argonne National Laboratory, Lemont, Illinois

1946 to 1950: Instructor — Advanced Mechanics, Purdue University, West Lafayette, Indiana

Responsibility/Experience

Mr. Helms is responsible for advanced technology vehicular engines at Allison. This responsibility includes the AGT 100 Project — DOE/NASA contract, Fuel Cell Advanced Technology Engine, and Coal Burning Turbines. The AGT 100 Project was planned and is directed under Mr. Helms' leadership. Ceramic materials technology is the major thrust of this program and he is a recognized leader in the application of ceramic components in heat engines.

Analytical Mechanics, including stress analysis, heat transfer, vibrations, weights, and computer analysis, was directed by Mr. Helms. Turbine cooling, including convection, film, and transpiration cooling methods, was implemented and developed under Mr. Helms. Lamilloy, an Allison invention, was conceived and developed under his direction.

Mr. Helms prior experience includes work on rocket motor cases and nozzles and turboprop, turbofan, turboshaft, and turbojet engines at Allison. Mr. Helms also worked on the Atomic Energy Commission reactor project for the Nautilus submarine.

INTRODUCTORY REMARKS

Thank you, Mr. Chairman, for this opportunity to present a status report on the General Motors-Allison Gas Turbine Division "Advanced Gas Turbine Technology Project" supported by Department of Energy (DOE) funding and contracted through the National Aeronautics and Space Administration (NASA) Lewis Research Center. I am Gene Helms, Chief Project Engineer, and am responsible for the AGT 100 Project. Today I have prepared a summary of activities for 1985 and a projected 1986 list of activities.

OBJECTIVES AND KEY TECHNOLOGIES

The Allison Advanced Gas Turbine (AGT) Technology Project has objectives that include the demonstration of a "proof-of-concept" automotive engine. This engine will have the capability of producing 30% improvement in fuel economy in 3000-lb automobiles, will operate on alternate fuels, and will meet 1986 and beyond automotive emission requirements. In addition, competitive initial and life cycle costs, reliability, performance, and noise and safety criteria for automobiles are goals for this project. Figure 1 shows the project objectives and the proof-of-concept engine with ceramic components applicable in the Pontiac A6000 and Fiero automobiles.

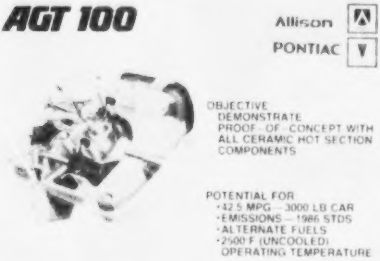


Figure 1. Advanced Gas Turbine Technology Project

Figure 2 shows an advanced CPC automobile that can also use the AGT 100 engine.

Figure 2. The advanced CPC automobile

Marketplace criteria are used at General Motors in planning and implementing high risk, high payoff, long-range technology projects. Allison adhered to these criteria in planning the AGT 100 Project. These criteria are cost, performance, and reliability.

Key technology areas identified and being pursued vigorously are:

- ceramic turbine components
- small scale gas turbine aerodynamics

Ceramic Turbine Components

Ceramic component development is the new and innovative technology area that will determine the future practicality of automotive gas turbines. It is necessary that ceramic components with high temperature capability replace the prohibitively expensive superalloy metals currently used in gas turbine components. The high temperature capability is necessary for improved engine performance. Superalloy costs are prohibitive because they contain significant levels of strategic materials such as cobalt, chromium, nickel, molybdenum, tungsten, and manganese. None of these costly, strategic materials are found in the silicon carbide, silicon nitride, oxides, and silicate components being developed in the AGT 100 Project.

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Aerodynamics

Since the automotive gas turbine engine has smaller components than ever before employed in a high performance production turbine engine, small scale gas turbine aerodynamics are important. Simultaneously, the automotive application requires high aerodynamic component efficiencies over a broad power range, with the highest efficiency required at part speed and power conditions. To illustrate the small size, the average automotive power usage is 14 horsepower (hp) (for a 100-hp engine) and most automobiles never use maximum power, since it is incorporated for acceleration, hill climbing, and other emergency power operations.

ENGINE TECHNOLOGY EVALUATIONS

Heat engine experience has shown that component technology is only valid when proven in an actual engine operational environment. This fact of development has been obvious in all engines because of the inability in component test rigs to duplicate the unique transient (a key to ceramic component suitability) operating characteristics of an actual engine and to reproduce working component interrelationships associated with aerodynamics, heat transfer, control, and mechanical factors. For these reasons, proof-of-concept engines complemented with component rigs, carefully chosen for screening and proof testing, are included in this project to prove that new ceramic and aerodynamic component technologies have been established in sufficient depth for usefulness to industry. Allison has designated its engine the AGT 100. Figure 3 is a photograph of the AGT 100 engine on the test stand in Indianapolis. The engine weighs less than 300 pounds, develops 100 hp, has two shafts, is regenerative (recovers waste exhaust heat), and is compatible with any type of transmission (manual, automatic, or continuously variable). The engine and accessory arrangement can be used interchangeably to replace current General Motors 2.8 Liter V6 or 2.5 Liter L4 spark ignition engines in mid-size automobiles (approximately 3000-lb weight class). Allison assessments of reliability, performance, control, and cost trade-offs have favored the two-shaft gas turbine engine for vehicle applications where constantly changing power requirements are placed on the power train.

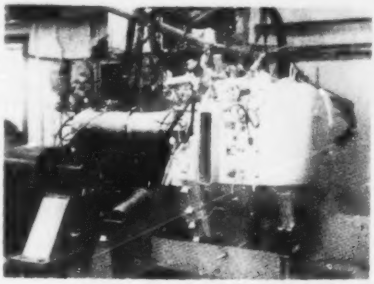

Figure 3. AGT 100 engine

PROJECT TEAM

Pontiac Motor Division of General Motors is an Allison partner in the AGT 100 Project. They have established the STE6000 and the new Fiero automobile as candidate applications for the AGT 100. Pontiac provides the expertise that ensures producibility, marketing, and cost analysis and gives continuing guidelines to Allison for achieving engine and component improvements to meet marketplace requirements.

Allison has worked on ceramic materials development projects sponsored by DOE/NASA since 1976. The SOHIO/Carborundum Company, Corning Glass Works, and GTE Laboratories have been prime suppliers of ceramic components on NASA/DOE projects including the current AGT 100 Project. More than 9,400 hours of Allison Model 404 engine running have been accomplished in the DOE/NASA CATE (Ceramic Application in Turbine Engines) Project using Corning regenerators and SOHIO/Carborundum silicon carbide and GTE silicon nitride flow-path parts. The AGT 100 Project enlarges on the CATE technology base in ceramic components. Additional companies supplying ceramic components for the AGT 100 Project are shown in Figure 4.

PARTS NAME SUPPLIER		[illegible]	CORNING	GTE	KYOCERA	NORTON	ASAHI	AMERCOM	COORS	AC SPARKPLUG	NGK	PURE CARBON	[illegible]	SEP	[illegible]
GASIFIER TURBINE	ROTOR														
	SCROLL														
	OUTER BACKPLATE														
	INNER BACKPLATE														
	VANE														
	SHIM														
POWER TURBINE	ROTOR														
	SCROLL														
	OUTER BACKPLATE														
	INNER BACKPLATE														
	VANE														
	SHIM														
COMBUSTOR BODY															
DILUTION BAND															
DOME															
REGENERATOR DISK															
BULKHEAD															
INTERTURBINE COUPLING															
EXHAUST COUPLING															
SHIM															
PISTON RING															
THERMAL BARRIER RING															

Figure 4. AGT 100 ceramic component suppliers

Allison subcontracting practice has placed development and parts subcontracts with only American ceramic suppliers. Foreign purchases of parts have not involved development funding.

PROJECT STATUS

1985 produced continuing advancement in ceramic component and engine development. Significant accomplishments include:

- 177 hours of AGT 100 engine testing on individual ceramic components (410 hours engine test time in program) (see Figure 5)
- 35 hours of engine testing of a silicon nitride ceramic turbine rotor (see Figure 6)
- Demonstration of methanol fuel in the AGT 100 combustor (this is the fourth fuel including DF-2, JP-5, and coal)
- First AGT 100 engine testing of a Corning Glass Works composite ceramic turbine backplate (see Figure 7)
- First combustion testing with a silicon carbide fiber imbedded in a silicon carbide matrix made by Societe Europeene de Propulsion (see Figure 8)

- Engine testing of SOHIO Carborundum stationary hot gas path gassifier ceramic components (see Figure 9)
- Engine testing of Carborundum silicon carbide turbine rotors (see Figure 10)
- Nondestructive evaluation (NDE) scanning photo-acoustic microscopy results — 20 to 30 microns (μ) surface defect identification
- NDE high frequency ultrasonic (50 mega-hertz) testing 200μ defect identification in very thick sections (3 to 4 inches)
- NDE real time micro-focus x-ray results with 20μ-50μ defect identification
- Improved yield of ceramic parts from 11% to 50% in making turbine rotors and increased Weibull Modulus from 7 to 11
- Hot isostatic processing of both silicon nitride and silicon carbide rotors

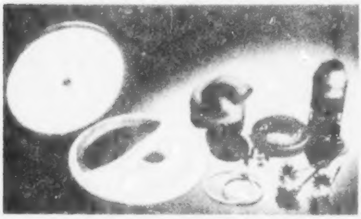

Figure 5. AGT 100 ceramic components

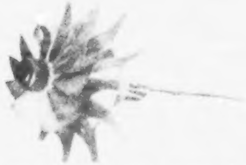

Figure 6. Silicon nitride gasifier rotor

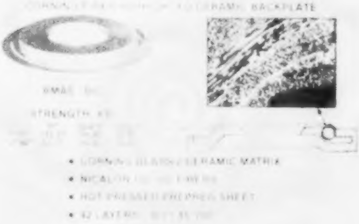
CERAMIC BACKPLATE
STRENGTH
• CORNING GLASS/CERAMIC MATRIX
• NICALON FIBERS
• HOT PRESSED PREPREG SHEET
• 42 LAYERS

Figure 7. Ceramic backplate

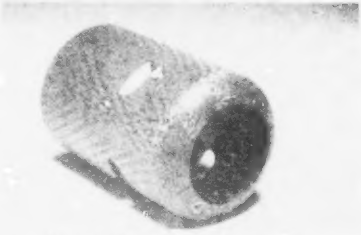

Figure 8. SEP silicon carbide fiber with silicon carbide matrix combustor

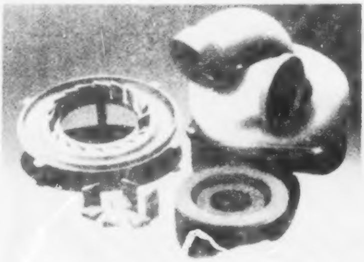

Figure 9. Carborundum silicon carbide stationary parts

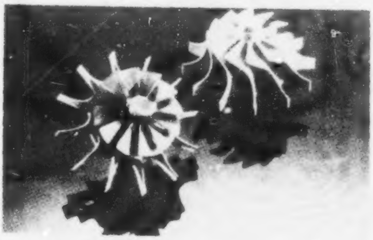

Figure 10. Carborundum silicon carbide turbine rotors

Alternate fuel capability is a significant issue for the AGT projects. Figure 11 shows measured emissions on DF-2, JP-5, and methanol fuels for the AGT 100 combustion. Note that methanol yields lower CO and NO_x emissions than DF-2 and JP-5 (gasoline will be nearly identical to DF-2) and that the DF-2 and JP-5 fuels yield emissions less than 1986 National Standards. These data show the turbine to be a very low polluting heat engine for automotive use.

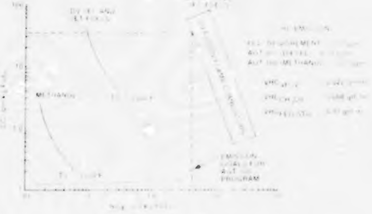

Figure 11. Premixed prevaporized AGT 100 combustor

The NDE capability indicated has progressed so rapidly that we now have the problem of differentiating between "critical" and "noncritical" flaws in ceramic components. This art is relatively understood in metals but is not understood yet in the structural ceramic component area. Figure 12 shows a flaw in silicon carbide. Interpretation of "flaw size," "flaw location," "cyclic loading at the flaw location," and "flaw geometry" must all be considered in assessing "good" or "bad" components. These new criteria are a measure of the newness of the technology being evolved in this unique program.

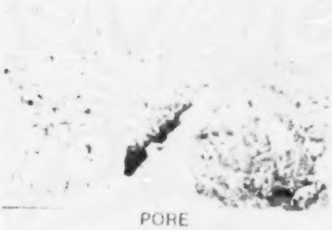

Figure 12. Silicon carbide defect

1986 AGT 100 Project Goals

DOE, NASA, and Allison have agreed that in 1986 Allison shall place emphasis on achieving the following proof-of-concept goals:

- Run the AGT 100 with all ceramic hot flow path components for 100 hours at temperatures up to 2200°F using DF-2 fuel—with subsequent short time operation at peak material limiting temperatures
- Measure emissions over a range of engine conditions
- Demonstrate combustor performance with alternate fuels
- Perform systems analysis based on engine test results and measured performance parameters to calculate the MPG potential at the Reference Engine Design conditions

Allison believes these goals are realistic and intends to successfully achieve these results.

AGT 100 SCHEDULE

Figure 13 shows the AGT 100 Project schedule with continuous concentrated effort on ceramic component development and intermittent effort on turbomachinery development. The ceramics effort has easily consumed the major portion of this $58 million plus program with significant funding dedicated to:

(1) U.S. ceramic supplier development activity,

(2) the characterization and analysis of ceramic materials and components,

(3) the establishment of new design methodology,

(4) new, sophisticated inspection techniques,

(5) new ceramic components testing rigs and test methods, and

(6) achieving an engine test bed that can prove the ceramic component technology readiness for movement into both military and commercial products such as heat engines.

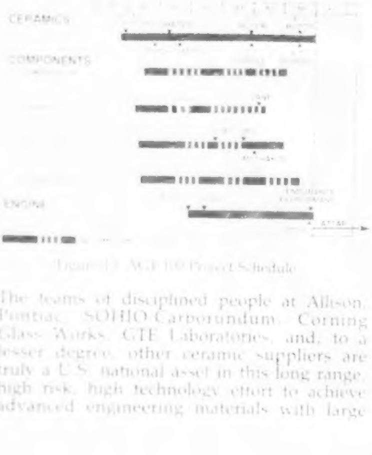

Figure 13. AGT 100 Project Schedule

The teams of disciplined people at Allison, Pontiac, SOHIO Carborundum, Corning Glass Works, GTE Laboratories, and, to a lesser degree, other ceramic suppliers are truly a U.S. national asset in this long range, high risk, high technology effort to achieve advanced engineering materials with large future payoffs in advanced heat engines. Of equal importance are the teams of disciplined experts on the AGT 101 Program conducted by the Garrett Turbine Engine Company. Allison wishes to applaud the efforts of the U.S. Congress, the Department of Energy, and NASA for their remarkable foresight, determined support, and competent direction of both AGT teams in this new, high technology effort. These two teams of experts have two of the best capabilities for evaluation of advanced ceramic components in the world today.

It will be noted on the schedule that an arrow going beyond 1987 is labeled ATTAP. An "Advanced Turbine Technology Applications Program" (ATTAP) is envisioned to continue the excellent work initiated in the current Advanced Gas Turbine Technology programs and is to be implemented by government to be complementary to both NASA and DOE generic basic ceramic research in improved monolithic and composite ceramic materials. The "ATTAP" will provide the evaluation means for establishing the technology readiness for the second and third generation of ceramics that are pointed toward advanced products for American industry.

Where Do We Go in the Future?

The current U.S. government sponsored AGT program and earlier U.S. government sponsored programs (such as CATE) have provided a large catalytic momentum to develop ceramic components not only in America but also in competitive overseas countries such as Japan, Germany, Sweden, and England, among others. The emphasis placed on ceramics, especially in Japan, has produced a real challenge to the United States to keep our lead in structural ceramics for heat engines. Japanese ceramic effort encompasses large efforts by industry, government, and academia in Japan. Their current capabilities in ceramic component manufacturing may be superior to the U.S. effort. The Japanese dedication to achieving superiority in structural ceramic parts, such as they now possess in electronic ceramic part manufacturing, is verified by many U.S. government, U.S. industry, and U.S. academic visitors to Japan. Also, the current AGT teams are now evaluating Japanese as well as American-made ceramic turbine components with initial results favoring the Japanese components.

The ceramic effort in the United States is likely to slow significantly if federal government support for ceramic component development is withdrawn or substantially reduced. Such a reduction may reinforce the commitment by overseas ceramics developers to the degree that the U.S. could eventually become heavily dependent on foreign sources for those components, as has occurred, for example, in the case of electronic componentry.

In order to minimize such a future risk, it is strongly recommended that the ATTAP program be continued for at least five years and that federal support be provided at a level that will assure continued progress through the full use of existing manpower, facilities, and equipment.

We recognize the need to reduce the federal deficit, but we are confident that a proper balance can be achieved in helping to meet that objective as well as our goal of worldwide supremacy in ceramic technology.

ATTAP Technical Challenges

ATTAP will help to bring second and third generations of ceramic materials to a level of technical maturity so that U.S. industry could, with confidence, utilize this new family of ceramic engineering materials in automotive gas turbines, other heat engines, and in many military and commercial applications.

The ATTAP technical challenges are as follows:

1. Design methodology
    a. Monolithic ceramic design methods are beginning to be applicable to components although our data base is very small and needs reinforcement. The attachment of ceramics to metals requires additional work to achieve cost effectiveness and structural integrity.
    b. Composite ceramic design methods are in their infancy because of our inability to properly recognize the lack of homogeneity in the composite structure. New approaches are only now evolving and require significant development.
2. Materials development
    a. Improved starting powders to make better components are just beginning to evolve from government and private industry projects to yield improved strengths required in monolithic ceramics. Processing and evaluation of components from improved powders are imperative.
    b. Iterations on basic processing methods are required to achieve cost effective components. The component yield today is less than 50% on critical components as compared to a required yield in production of over 95%.
    c. Incorporation of NDE methods in processing as well as in final component inspection is an art requiring significant effort to provide interpretive baseline data and develop quantified methodologies for component acceptance/rejection.
    d. Machining methods that can be incorporated in an optimum fabrication processing to minimize component cost must be pursued.
3. Testing

    Sufficient testing of ceramic components in the realistic engine environment is required to prove the reliability of ceramic components at advanced engine operating temperatures. The AGT 100 and AGT 101 are excellent test devices to achieve this goal.

Figure 14 summarizes these needed technology efforts.

- •DESIGN METHODOLOGY
  - —MONOLITHIC
  - —COMPOSITE
- •MATERIALS DEVELOPMENT
  - —IMPROVED STARTING POWDERS
  - —BASIC PROCESSING METHODS
  - —NDE METHODS
  - —MACHINING METHODS
- •TESTING

Figure 14. ATTAP technical challenges

Mr. Chairman, I wish to thank you and this committee for this opportunity to review the status of our current program and to discuss with you our views on the proper method for continuing government-industry thrusts for advanced ceramics programs.

Mr. LEWIS. Thank you, Mr. Helms.

The question I will ask both of you gentlemen—Dr. Gratch, do you have any testimony you would like to provide?

Mr. GRATCH. No. I am here just to answer any questions, Mr. Lewis.

Mr. LEWIS. OK. I asked the Stirling team, what would be the benefit of funding both AGT teams in the follow-on ceramic development programs?

Mr. BOPPART. Probably the best answer to that is to look at the accomplishments of the program so far, and I think that it is evident that the Government and industry have derived very significant benefits from having the two programs that have existed so far. As Mr. Helms has indicated, they have pursued in many ways alternative approaches in an area where the territory is so unknown that a clear path cannot be laid out far into the future.

The element of competition undoubtedly has some beneficial effect, but I think that you would have only to look at the rather outstanding progress that has been made in the program so far in the competitive, parallel, two-approach environment to see the kind of benefits that could be expected in the future.

Mr. LEWIS. Do you believe that the Department of Energy's proposed $4 million program would be sufficient to cover your overall program?

Mr. BOPPART. We would recommend a level of funding on the program of—for a two-contractor program—of about $9 million a year, per contractor.

Mr. LEWIS. Do you concur with that, Mr. Helms?

Mr. HELMS. In general I concur with that, yes, sir. We have not named a specific value in our recommendation to you but we do feel that certainly the program we have had, we signed a contract with the Government in 1979 and in that contract it called for support to the level of maybe $15 million per year for us, and I think maybe $13 million for the Garrett people in their top year.

We have not received that level of funding in any year to date in our current program. I think this year each of us get about $7 million per year. We feel that the effort that we have this year is minimally sufficient and at a lesser funding is insufficient to maintain a thrust that would help us to compete with the kind of activity that we now see out of the Japanese community.

Mr. LEWIS. I guess I have a question to ask you, Mr. Helms. In view of the arguments put forth by Mr. Nightingale on the Stirling engine, which they now can substantiate 41.5 miles per gallon of fuel, and the lack of interest shown by Detroit or General Motors in that engine, should we—would it apply to AGT as well? Should we continue to fund these programs if there is a lack of interest showing coming forth, in these high gas mileage engines in cars?

Mr. HELMS. Let me—may I answer that question, please?

Mr. LEWIS. That's fine.

Mr. HELMS. Thank you for asking that question. I have wanted somebody to ask me that question for years. [Laughter.]

I would compliment Mr. Nightingale and MTI for the brilliant work they have done with the Stirling engine. They indeed have done unique and clever and innovative work, but let me observe, sir, that in the 1960's General Motors spent many hundreds of millions of dollars trying to make a Stirling engine work in an automobile, and our conclusion at that time—and we stopped all work on Stirling—was at that time we could not get through those three wickets that we set up for ourselves to have a product: cost, performance, and reliability.

At the time that the Government initiated the Stirling program, they did indeed ask General Motors, Ford—I don't whether they asked Garrett or not—and Chrysler and AMC to bid on that program. General Motors declined to bid on that program because we saw nothing then, as we see nothing now, that says that's going to be an automotive powerplant. It is an extremely difficult engine to meet those three wickets—cost, performance, reliability—and that because of the heat transfer fluid that is used in the engine, the inherent leakage, the demands for reliability, and other factors.

Now I can't say that breakthroughs haven't been made that I am not familiar with, that could make it fit into those three wickets, but to the best of my knowledge those breakthroughs still are not there. I'm sorry to say that. I sincerely believe the Stirling engine has applications in many other arenas. If you look at the use of a powerplant in a mine, it demands a quiet, fuel-efficient engine. The Stirling may be an ideal engine to use in a mine.

We to this day, though—let me go forward now with another statement—have maintained within General Motors continuing GM-sponsored programs where we feel the engine does have applicability in the automotive arena, and through all of this AGT program we have maintained automobiles operating on gas turbines. Today I could take you for a ride, sir, in at least three different vehicles, General Motors vehicles, that do have gas turbines in them—a 1985 Camaro with a gas turbine in it, a 1979 Cadillac that is powered by a coal-fired gas turbine, a 1977 Buick Regal that is powered by a gas turbine.

We did choose to bid on this gas turbine activity because of this ceramics technology and the impact it could have in making the turbine a truly viable powerplant. The reason General Motors has not gone into production with a gas turbine in the past is that the superalloy materials were too expensive and in too short a supply to justify considering a turbine as an automotive powerplant. With the advent of ceramics and with the unveiling of the kind of technology that's coming out of this program, it has the possibility of making the turbine a future powerplant for General Motors.

We have had a continuing program within General Motors for gas turbines for automobiles since 1952, and our investment in that kind of powerplant is huge. This ceramics technology I believe is a key technology, and like a former speaker said, I hope that our future look at budgets considers the shock-type environment like we saw in 1973, 1974, 1975, 1979, and 1980, because it's my opinion that what's happening today with oil prices is the lull before the storm. They're setting us up again for the next round of blackmail, in my opinion, and I hope the next time we will be able to respond with powerplants and fuels that will make us far less susceptible than we were the last time we got this oil shock treatment.

Mr. GRATCH. Mr. Lewis, if I may amplify on that answer from a Ford point of view. Ford has also worked on the Stirling engines in

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the past. We currently are working on gas turbines, both in this project and with some independently Ford-funded work.

We have a large program on adiabatic diesels. Several years ago we concluded that the gas turbine and the adiabatic diesel both had all the potential advantage of the Stirling as far as automobile. They had the potential for the fuel economy, in which we are still very interested. Don't believe anybody that says anything to the contary, because the only reason that we are funding the adiabatic diesel program is because of its fuel economy potential. We have shown not only that these two powerplants—in the case of the adiabatic diesel, we need several modifications—can run on alternate fuels, but we have demonstrated even to the subcommittee some of our work on alternative fuels, so I believe that the subcommittee knows that Ford is capable of alternative fuels in other powerplants.

In our technical evaluation the powerplants that we are working on, and practicularly the gas turbine, have all the advantages of any competitive powerplant, but there are still some other advantages. The gas turbine in particular has the potential of great technological fallouts in other areas. The work in ceramics which we are doing for the gas turbine is directly applicable to our adiabatic diesel program. It is applicable to such other automotive applications as ceramic turbochargers. There are other potential fallouts of the gas turbine outside of the automotive sphere that Mr. Boppart could discuss in much greater detail than I could, and therefore we think it is preferable.

One important thing is that both the gas turbine and the adiabatic diesel do not require the use of scarce high-tempertature metal alllows, and that is one of several reasons. Another reason that we chose these is that future trends in design of automobiles. In order to take advantage of improvements in aerodynamic, are incompatible with very large radiators such as would be required, for instance, in the Stirling engine.

Mr. LEWIS. Mr. Helms—thank you for that explanation. Dr. Gratch—I guess philosophically I want ask you a question. It may not even apply to what we are talking about today, but you brought out the fact that you hope that we are in better shape if we have another fuel oil crunch.

I don't think we are going to be. I think we are going to fall right into the same cavern that we did in the seventies, if OPEC decides to lead us to the slaughter in that area again and come up with fuel shortages. I don't think we learned a thing. The American automotive industry continues to petition Congress to relax the restrictions on gas mileage, and through the many issues that I have read from all of the American motor companies, as far as cars for the future and the near future, I don't see anything about this engine, looking at 41 miles or 41.5 miles per gallon.

I see all kinds of sleek body desigas and three-wheel vehicles and four-wheel vehicles, and most of them glass, and looking at getting lighter and plastics for the bodies and things like that, but I never really find anything about the powerplants. We are still, today, operating with a basic internal combustion engine. The only thing we have really improved is maybe the ignition systems, and there are some questions about that when you try to get them repaired at the places.

So I guess what I'm saying, is General Motors really interested in applying this technology as rapidly as possible to get it into vehicles, so that we can—regardless of whether we have a glut on the oil market or not—get a better-performing engine to provide more gas mileage, and still provide the rides that we are used to today with what we have?

Mr. Helms. Thank you again for that question, sir.

Mr. Lewis. It was a long-winded one.

Mr. Helms. It happens to be one that I have thought a lot about, and I think there are some terrific answers to your question.

Let me say to begin with that I believe that the program we have had has stimulated General Motors—and this is not the only stimulus, so please don't get me wrong, but this kind of program has stimulated General Motors to make significant advances in internal combustion engines. I think that has absolutely been true.

I think General Motors is extremely proud of the fact that they have now more than doubled the fuel efficiency of their automobiles and their engines, sir, and that the advances are not restricted to just a few advances in ignition. I think if you take apart today's internal combustion engine and look at it, you will find it is a tremendously more sophisticated device than it was a few short years ago.

If you look at the power per pound of engine today, it is a tremendously more sophisticated powerplant than it was a few short years ago, so I don't believe your assessment of the ICE engine standing still is a fair one. I think that there has been tremendous progress, and I think there continues to be progress, such as direct fuel injection being introduced into internal combustion engines.

Now I do believe that your standards should be relaxed because they were written at a time when there was true energy crisis, theoretically—theoretically, I say, because I think there is question as to limited crisis—but I do believe the technology that we are developing today is going to find its way into internal combustion engines, as well as into turbines, as well as into other kinds of engines. The technology base that is being derived in this program is super critical to use of similar technology in diesel engines.

This brochure that I have here, I picked up just yesterday. I would have included that as part of my testimony if I had had it before, but—would you like to carry this up to the chairman?—you will find in that brochure many pictures of ceramic components that can be used either in diesel engines, ICE engines, or gas turbines. The design requirements come out of the technology that is being established in this program.

I can unequivocally state that when we started this program on ceramics, many of the people in my corporation looked upon me as a visionary and told me how impossible our task was, and today many of my colleagues in General Motors are asking about ceramics and are sincerely endeavoring to apply ceramics in ICE engines.

Mr. Lewis. I have taken a lot of time already. Mr. Packard, why don't you ask some questions?

Mr. Packard. Thank you, Mr. Chairman.

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Would the private sector pick up these projects if funding were discontinued?

Mr. GRATCH. Is that addressed to me, by any chance? You are looking at me, Mr. Packard.

Mr. PACKARD. I will ask Ford first.

Mr. GRATCH. At this point it is questionable whether Ford would pick up vigorously the work on the gas turbine. As I mentioned earlier, we are doing some work on the subject with our own funds. I would expect that to continue. I doubt that that would allow us to remain competitive, for instance, with the Japanese. The reason is that at the present time the gas turbine still represents a very high-risk technology.

There are some serious questions as to the durability of the components. Mr. Helms referred to the need for second- and third-generation materials. The reliability and reproducibility is extremely important. I am somewhat embarrassed to say that while we have gotten rotors that we could cold-spin at 110,000 revolutions per minute, we would have to make maybe 10 of those to get 1 good one. Obviously you cannot go in production on that basis.

It is a matter of cost, and that will require some rather fundamental advances. The total fabrication of one of those rotors is a matter of weeks. Even with complete automation, the investment cost to produce such rotors in automotive quantities would be staggering. Some of the work that we are doing independently and some efforts that we have for joint ventures with other ceramic companies are aimed just at developing suitable manufacturing processes. We believe that without the ATTAP program, the risk involved in this technology would be too high for private industry to pick up the load.

Since I've got the mike, I can't resist saying—I always like the role of a maverick—I have to differ with my two colleagues at this table on the issue of two versus one contractor. If we could talk about business as usual, I would also support two contractors. In times of tight budget constraint, when our company as well as many other people consider that the No. 1 priority in the country is to reduce the deficit, I couldn't in good conscience recommend the added cost of having two programs instead of one. I'm sorry to disagree with Mr. Helms and Mr. Boppart.

Mr. BOPPART. Let me go back to your question. I would like to put it, if I may, in a historical perspective. As Mr. Helms has indicated, at the time that the AGT program began, well-informed persons of good judgment could very legitimately question whether it was possible to build an all-ceramic gas turbine or whether it could be characterized in any real sense as a promising commercial technology.

That which will have been accomplished by the end of this year is clearly to give positive answers to both of those questions. There is no question that an automotive ceramic gas turbine can offer very significant benefits to the automotive industry and to the country. Now what is needed and what is planned in the ATTAP program is to broadly develop the ceramics base to in fact support an industrial use of this technology.

Looking at the requirements, I think you would have to conclude that the basic technology development work, the basic manufactur-

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ing technology, process technology development work which is needed in the next period is not that which is at all effectively done on an individual basis by industry. Although all of us who have been involved in the program and who are involved in the ceramics would have strong motivations to progress as rapidly as we could, there can be no doubt that the progress which would be achieved without ATTAP would be very small fraction of that which we could expect with the program.

Mr. Packard. It would appear to me that $9 million a year is really not a lot, in terms of the cost of major auto companies, and particularly when you are talking and looking at not just the next generation but as you have already alluded to, it may become the next two or three generations of engines, but I won't get into that.

I am not certain that I understand the fundamental differences and benefits of ceramic turbine engines versus the conventional engines that we now deal with.

Mr. Boppart. OK. That is, very simply, gas turbine engines require operation of some of the components at continuously very high temperatures in order to achieve their benefits of light weight and high performance.

Mr. Lewis. Excuse me. I have an emergency.

Mr. Packard. That's OK. Thank you.

Mr. Boppart. In the conventional gas turbine engines and the ones that power the transport planes that we fly around in, that is accomplished by using rather exotic, rare, and very expensive metallic materials. It is also made possible in large engines by having complex internal cooling systems built into the high temperature parts.

Neither of these things is possible in small engines suitable for automobiles. The physical size of the components is too small to permit these complex internal cooling passages, and the economics of the situation would not permit the cost either of that or of the basic material. Therefore, the role of ceramics is, ceramics is uniquely the thing which makes gas turbines possible in the small size and in the economic cost required for automotive.

Mr. Packard [acting chairman]. Simply to withstand the heat?

Mr. Boppart. Yes.

Mr. Helms. But I think an important point—if I just may supplement John—is that with the metals, if we could run cool parts, we still are limited in the operating temperature that we can achieve with metals, and let me give you an example.

Typically turbine engines today run at 1,900 degrees Fahrenheit to 2,400 degrees Fahrenheit. The turbine engine is most efficient if it could run at 2,500 to 3,000 degrees Fahrenheit. That is when you really excel with performance and fuel efficiency, is when you can achieve that level of operating temperature.

Now it's easy to observe that most metals melt at 2,400 degrees Fahrenheit, even the high strategic material type materials, so the ceramics open a whole new range of possibilities relative to fuel efficiency in the turbine, but also in other kinds of powerplants as well, sir.

Mr. Packard. It appears that the objectives, the fundamental goals and objectives of the Stirling engine and the Allison engine and the Garrett engines are all essentially the same—fuel economy, performance, and you mentioned others, the cost and the reliability. There must be overlaps, significant overlaps, in these three projects, research projects.

Mr. **HELMS**. To date the Stirling uses no ceramics, sir.

Mr. **PACKARD**. That's true.

Mr. **HELMS**. I think that's correct, isn't it?

Mr. **PACKARD**. True. No, it doesn't. I agree, but still the fundamantal goal is the same.

Mr. **HELMS**. Yes.

Mr. **PACKARD**. Fuel efficiency and the cost, performance, and reliability that was mentioned by you, Mr. Helms. Is there not, then, a direct overlap between the three projects, certainly the two here, but even in the goals and objecltives of the Stirling engine.

Mr. **BOPPART**. There is a clear commonality of goals. However, to put it most simply, there is absolutely no commonality in the approach. They are two absolutely different approaches——

Mr. **HELMS**. Technologies, yes.

Mr. **PACKARD**. But they are still, because they have the same goals, they are still competing then with one another in the commericial market.

Mr. **BOPPART**. It depends on who you ask. Clearly if you ask the automotive companies, they have made and continue to make the decision that it is not competitive; that the gas turbine is the only——

Mr. **PACKARD**. Let's look beyond the automotive, because again our discussion with the Stirling engine——

Mr. **BOPPART**. In other areas clearly the Stirling has many promising attributes.

Mr. **PACKARD**. So the Garrett and the Allison engines, the ceramic concepts are primarily looking at automotive applications rather than aircraft.

Mr. **BOPPART**. No. Let me clarify. The program is focused, of course, on the automotive size, but we have conducted a side study under NASA sponsorship which has shown very good application of this type of engine to revitalizing the small aircraft end of the general aviation industry, which has become very dormant, as you know, because of the economics and the requirement for aviation gasoline. Because of its unique potential for low cost, simplicity, and very high fuel efficiency, the gas turbine developed in this automative concept has very wide application in generator sets, in tractors, very wide application.

Mr. **PACKARD**. It's obvious that you are very optimistic for the future of ceramics.

Mr. **BOPPART**. Yes.

Mr. **PACKARD**. I have difficulty understanding, then, why the commitment of the industry is not greater in terms of the private sector, in seeing this as the future for their, to remain competitive, and let me get into that whole aspect of competitiveness and look at Japan as a particular focus. Even some of the component parts have already been purchased from Japanese manufacturers, the rotor and some others. Is that correct?

Mr. **BOPPART**. That's correct.

Mr. PACKARD. That's because they have—well, I thought I understood from your testimony because they were considered to be superior to what we have been able to do.

Mr. BOPPART. Because they are able to provide them, yes.

Mr. GRATCH. They have a national commitment.

Mr. PACKARD. What?

Mr. GRATCH. They have a national commitment.

Mr. PACKARD. I guess that's what I was just alluding to a moment ago. It appears that you are telling us here that this is the future for the automobile engine, but I don't feel that commitment from the industry, not from the two representatives here, to the point that you are willing to really stack your future on it. That gives me some concern, particularly in an era when we are looking at protectionist type of pressures in terms of world competition in the automobile industry itself.

One of the concerns we have had, and I think you have heard us express it before, is that the industry needs to be willing to compete in that world marketplace from a competitive point of view and a commitment point of view, rather than from a protectionist point of view, and I think for the most part you would agree with that. I guess what I am asking is, how do you see us moving in this highly competitive area. Already it has become obvious that this is going to be a highly competitive area. Are we going to joint venture with Japanese companies as an alternative? Is Japan investing higher levels of dollars or capital, both at the private and the public sector? Where do you see the competition coming down, let me ask?

Mr. GRATCH. If I may comment on that, in order to answer that I would like to give both a little past history and future plans. Ford Motor Co. has been working on ceramic applications in engines for a long time, since the sixties. We have invested, of our own dollars, more—as far as I can determine—than DOE has invested so far. We are still committed to this, to the extent that we have a ceramic engine program on adiabatic engines which is completely funded by Ford. We are committed sufficiently to that so that we are in the process of negotiating a joint venture, all United States, all American, for the commercialization of these ceramics. Unfortunately, because of SEC regulations and others I cannot say more until that is completed.

So that is definite commitment. Until very few years ago we felt that technologically we are ahead of any other country in the world. What we have found in the last few years is that because of the national commitment of the Japanese, while probably as far as basic technology at most they have caught up with us, the thing they have is that they can fabricate those parts readily.

When my friend John Boppart asked me to deliver 10 rotors, I wring, my hands and say, "Would you be satisfied with one in 3 months?" When he asked one of the Japanese companies, they say, "Only that much?" and "Is a month from now too late?" Our facilities are not enough to produce. They use the same processes, the same methods. We have tested their materials. In some cases they are a little better than ours, in some cases a little worse. We do not have now the facilities to produce them at a fast enough rate that they can be evaluated, tested, and so forth.

Mr. Packard. Why do we not have them and the Japanese do?

Mr. Gratch. Because they have a different economic system, they have a national commitment. MITI is putting in effort, and they are able to invest—for instance, they have put in production some components which, from what we know, in fact cannot be competitive. If we did it, we would do it at a loss, but they can do that because of their system.

Mr. Packard. Mr. Helms, how does—does GM, intend to be competitive in this ceramic engine field, and if so, how?

Mr. Helms. Yes, sir. I think the answer is yes, and you might appreciate that we have a division which is called A.C. Sparkplug, and today we make 1 million spark plugs per day, each one of which has a ceramic in it. We also have oxygen sensors as part of our emission control, which is again a ceramic.

I think the issue here is that now we are talking about structural ceramics, ceramics that now do the job that historically metal parts have done. As we unfold technology, we increase our investment.

If I may, sir, may I show you two or three charts that I have prepared to address the issue that you have asked about?

Would you show that first chart on risk, please?

Mr. Packard. The chairman is not here to object, so I think we can go ahead with it. [Laughter.]

Mr. Helms. We have to, you know, address the use of our discretionary moneys the same as you do, and we attempt—and I have to observe with you that this is a very subjective type evaluation—but we attempt to assign risk as we address each product and each future thrust. We have generally identified seven risk areas, and the very top area indicated there is a zero risk situation. That's a case where we have similar parts in production and we know complete specifications. We require no modifications, really, and state-of-the-art.

At the other end of the line is what we call critical risk, sir, and there we say "major breakthroughs in technology required with high probability of many unforeseen problems," and that is where we feel we started approximately in 1980 with this automotive gas turbine program.

Mr. Packard. Where are we at now?

Mr. Helms. I believe we are still in the areas of five, six, and seven sir. There are some parts that could even go to production and might be classified one, two, or three, because I would have to put spark plugs into the "one" category up there. OK? That is a stationary part. But if you look at the specific parts that we have been addressing in these automotive gas turbine programs, I feel most of those parts still fall in categories six and seven.

Now will you show the next chart, please?

Mr. Packard. Before you leave that, the next question has to be, then, what area do you have to operate in in terms of the level of risk to remain competitive in the world marketplace?

Mr. Helms. Oh, we have to be in that one, two, or three area to be competitive, and I believe that maybe some of the Japanese parts are over into those three and four areas, because they have marketed this year ceramic turbocharger, rotors not unlike the rotors we are talking about, in the Nissan XZ automobile, so I think they are ahead of us. We have no similar rotors made by U.S. companies in a production situation today.

Mr. Packard. Could it be because they are willing to operate in a higher risk——

Mr. Helms. That partially is a part of the explanation, sir.

I attempted here to show funding versus—and R&D funding is described in yellow and, again, measured against those seven levels of risk. In the blue I have attempted to show marketplace, and that in billions of dollars against R&D in millions of dollars. Again, I would identify our ceramics activity to be over in that six and seven area on that chart, and I think that is the area where shared funding between Government and industry is appropriate.

The last chart, sir, I would like to show you is this one. Again, I have shown percent industry money on the left-hand scale and Government money on the right-hand scale, and notice that we go from zero to 100 percent, and there is a line at the top that goes between the 100-percent bars, and I labeled that as "unique requirements." Certainly if the Government needs a new ICBM, we believe that should be 100 percent Government funding; however, if General Motors needs a new Fiero automobile, we believe that should be 100 percent General Motors money.

I put on there, then, two lines, one that is labeled "commercial defense" or "defense commercial" and one that is labeled "purely commercial," and the thing to note there is that I believe this ceramics technology effort that we have today has fallen on basically that "defense commercial" line because of the applicability of the technology. Maybe you go down that line on a cost-share basis, and maybe we could discuss different shapes of lines.

I show this chart to be a thought-starter on what is appropriate relative to investment by industry and Government. I am not smart enough, sir, to know exactly what the shapes of those lines should be. I would observe with you, however, that we have cost-shared already the program that was started when the whole technology was at the seven level of risk. There's no doubt about it, we are coming down that line somewhere, but there are no observable structural ceramic components in production today, so I suggest to you that the risk level is still in that five, six, seven area with these ceramic components, and the critical components of course are still in between that six and seven area, so I think it is appropriate for joint Government/industry funding of this effort.

Mr. Packard. I think the general attitude is—tends toward the concept that the Government ought to fund the high-risk areas, and that the private sector doesn't substantially commit themselves until they are into the lower-risk areas.

Mr. Helms. Yes, sir.

Mr. Packard. That may be a difference between Japan and the way we operate here, and it might be that—that might be why they get, one of the reasons why they get a competitive edge.

Mr. Helms. It may be easy to observe—and I hope you don't take this too facetiously—their Government activity is far smaller there than it is here.

Mr. Packard. Comment was made on the flaws—and we need to get on to the next panel—but the comment was made on the flaws in ceramics. I have had a little bit to do with ceramics in my own professional life, and most ceramic work is x rayed and you can pick up those flaws. I think I can tell you that the Japanese are very much committed to quality control, and they are leaders in that area, incidentally, as I am sure you know——

Mr. HELMS. Yes.

Mr. PACKARD [continuing].—And they are going to find that that is not going to be a deterrent in terms of the use of ceramics, the quality control aspect. They will solve that, I am convinced. Do you think that our industries will take that same approach?

Mr. HELMS. Yes, sir. My feeling is that we are well on our way to finding solutions, and we have developed now tools to finding solutions, and we have developed now tools—outside General Motors, I might add—that have remarkable defect identification capability.

Mr. BOPPART. If I might just make a summary comment on that, I think that it is clear to us—and I hope we have communicated it—that the particular combination of Government/industry effort that exists in Japan is being very successful in solving these problems and in advancing them toward a commercial capability. We strongly believe and support the DOE, that the ATTAP Program is the appropriate U.S. vehicle to achieve that and to maintain the advantages in technology that we have generated in the AGT Program.

Mr. PACKARD. I think there is general unanimity on that point.

One last question: Is there any payback contract similar to what we have just discussed with the Stirling engine?

Mr. BOPPART. No, because we have cost-shared very heavily on our program. If you look specifically at the Garrett/Ford Program, and I think the story is very much the same in the General Motors/Allison Program, within this program itself we have spent about 50 cents for every dollar that the Government has put in. Outside of that program, Ford for instance I know has invested over $30 million in ceramics technology over the years. There has been a very, very heavy contractor investment in the program.

Mr. GRATCH. If I may expand on that answer, if our hopes are fulfilled, the Government will receive much larger returns than any payback contract that I know of, because 50 percent of our profit will go to the Government, and we hope that our profits would be several orders of magnitude larger than any payback contract has provided for.

Mr. PACKARD. We might be looking ahead at the Tax Reform Act and how that affects that. [Laughter.]

Well, then I think that response requires another question, and that is, what kind of technology transfer from the end products here is going to be available to other companies—Chrysler, American Motors—or will there be some proprietary information available to the joint ventures that would not be open to the rest of the marketplace?

Mr. BOPPART. As Mr. Nightingale indicated, in our society with the open communication, clearly everybody has access to the results in some form. The advantage to continued sponsorship of work in this country and under the ATTAP Program is precisely that it will diffuse the technological development and the actual, practical ability to apply this technology broadly throughout the U.S. industry.

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Mr. PACKARD. That is almost an essential part of any Government funding program like this.

Mr. BOPPART. Yes.

Mr. HELMS. Yes, sir. The ceramics suppliers that we use, and I think that Garrett uses, even though they too are in the ceramics business, that technology that resides at Carborundum, Corning Glass, and other U.S. suppliers is available to anybody that wants to use their products.

Mr. PACKARD. Well, gentleman—does the staff, in the absence of other Members of Congress, does the staff have any questions that have not been asked?

Dr. MAXWELL. I would like to just clarify a statement that was made by Dr. Gratch earlier on the comparative advantages of the Japanese components in the advanced gas turbine rotor parts, particularly as compared to United States-manufactured components. At the present time are the Japanese components better, or are we able to prepare components or produce components equal to what they are now producing?

Mr. BOPPART. I will preempt, if I may, since Ford is one of several people from whom we are obtaining ceramic parts on this program, and I think the observation I would make is that the Japanese companies, particularly Kyocera and NGK—who as you know are respectively pretty much world leaders in electrical insulator ceramics, in the case of NGK, and in the ceramics substrates for electronics, in the case of Kyocera—have built on that base and have done a much better job than American companies have done so far of getting tied down and under tight control the process technology which is required to reliably turn out parts repeatedly and with consistent high quality.

Dr. MAXWELL. But specifically, as I understand it, the Japanese have provided both programs with component parts that allow achievement of the 2,500 degrees Fahrenheit and, I believe, 100,000 revolutions per minute criteria of those engines.

Mr. BOPPART. Yes.

Dr. MAXWELL. Have any U.S.-manufactured components equal that goal?

Mr. BOPPART. Yes, we have seen parts made both by our casting company with Garrett and by Ford, which we have not run in engines but which in spin tests have demonstrated the internal, the inherent capability, the stress capability. The problem, as Dr. Gratch very well indicated, is that the productivity within the United States suppliers is far less advanced than within the Japanese companies. As a result, it has been the Japanese suppliers who have been able to in fact give us the parts that we need to initiate operations.

Dr. MAXWELL. Mr. Helms.

Mr. HELMS. Paul, my evaluation criteria is very simplistic: If it works in the engine, it's good. If it doesn't, it's not so good. The only successful engine testing I have had on the most difficult ceramic part, the rotor, has been on a Japanese part. We have tried American parts; they have not yet worked.

Dr. MAXWELL. Thank you.

Mr. PACKARD. Thank you, gentleman. Mr. Boppart and Mr. Helms and Mr. Gratch, we appreciate your testimony very much.

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And we will ask Dr. Vincent Halsall to come forward, and let me also ask Dr. Victor Tennery to come and join with him, and we will have their testimonies in the interest of time, and then we will question them individually as necessary.

And we appreciate Dr. Halsall, vice president of Battery Division, Johnson Controls, Inc., from Milwaukee, we appreciate your being with us, and we will proceed with your testimony first.

STATEMENT OF DR. VINCENT M. HALSALL, VICE PRESIDENT, BATTERY DIVISION, JOHNSON CONTROLS, INC.

Dr. HALSALL. Thank you, Mr. Boehlert.

Mr. PACKARD. I'm not Mr. Boehlert, but that's all right.

Now with both of your testimonies, they will be entered into the record in their full content. You may handle it any way you wish. You can read from your testimony or you can summarize in any way that you wish.

Dr. HALSALL. Thank you, Mr. Boehlert.

We have submitted written testimony, and in brief explanation this morning I just want to introduce our testimony as it may perhaps be unknown. We are about a $2.5 billion corporation operating four main business activities. The one that I represent today is our Battery Division. The Battery Division of Johnson Controls makes about one-third of all the automotive, SLI, and similar starting batteries in our country. In addition, we manufacture a range of industrial products for the battery industry, and are pretty well spread throughout the Nation in all its population centers.

We are primarily a manufacturing corporation. We do not see ourselves necessarily as a super high technology, or a research-related organization. We attempt to develop what we need for the products now and in the future.

These are a few of the types of trademarks. Our corporation's name is not frequently seen on its batteries. These are original equipment products. As you can see, United States companies are mostly represented, plus the new Japanese on-shore manufacturers where we also supply their original equipment. I might say that the technology in these lines has been moving ahead very fast over the last several years toward higher energy density and greater reliability in an ever-toughening realm of requirements in our cars.

The way that the technology interfaces operate within the Battery Division consists of four basic engineering groups which overlap with our corporate research. Mr. Winelein, who is with me today, manages our Advanced Development Engineering Group. In turn, they draw upon the services of product design, process engineering, mechanical systems and equipment, and ultimately attempt to put products into our manufacturing system that gives us a lead in the world.

We are in a world technology battle without any question and lead-acid, while frequently considered not to be the highest technology type product in the world, has made very significant strides over the last 10 years. In total, a great deal of the efficiency gains have been encouraged, some supported, and of course the base lines are the best of all. Over the last 7 or 8 years a total of $5 million has been invested—about 35 percent of it funded by Johnson Controls and the balance with the support of the Department of Energy—over this time invested for the development of batteries for electric vehicle propulsion systems.

We have met the goals of the programs. We have, in fact, achieved specific energy improvements in excess of 60 percent, and see our way as not only to doubling cycle life of products—as we already have electrolyte circulation systems in place—but in addition we anticipate that not only vehicles like the Chrysler ETV-1, where we, Chrysler, and General Electric function together with a new propulsion system; the hybrid vehicle system, the HTV-1, again we supplied advanced powerplants with electrolyte circulation patterns; and have ended up with a range of specific custom-purpose design EV units that literally could, in place, drive vehicles today.

When gasoline prices are below $1, there is minimum incentive. On the other hand, as this particular slide illustrates, part of the lead market trends have swung over the past 5 years from 65 cents a pound lead to the present market level between 18 and 20 cents. In the course of the development partially funded by the Department of Energy, we were able to generate a process and a design system to produce a combination of lead and plastic grids that had the effect of taking 60 percent out of the weight of negative grids and in excess of 45 percent out of the weight of positive grids in single mechanisms where a single-unit machine, operating like a conventional caster, was able to move this far forward. This of itself had a 10 percent energy density achievement associated with it, giving away nothing in batter performance on the way.

I should mention that as part of that type development, we also have put production capability in place to produce units of that kind, and have in excess of 1 million batteries in the field in normal production service using that technology.

The specific energy levels that have been achieved are no longer considered adequate, and we have a set of goals to move the energy density and the life-cycle capability of this sleeping lead acid system significantly forward. We believe that in relation to relatively limited funding support, it would be possible for us to pursue the goal of guaranteed electrolyte flow systems whereby plates with total integrity may be allowed to transmit low levels of electrolyte by pressurized differentials within the cells, such that a further 40 percent yield in the active material utilization in the batteries is not only possible but we have made early stages of demonstration on single-unit cells that lend themselves to fitting within the EV-3000 and similar type models that I photographed before.

There is a need for some continuation of low-level support in order to enhance this. We do believe that sooner or later our needs for alternative energy systems will once more hit us in the face, and in this regard we believe that it's appropriate to have a continuing cost-shared relationship with the Department of Energy, hopefully in which a higher proportion of the cost than in the past would accrue directly to the development companies, as opposed to being absorbed by the administrative arms of academia and places like this.

Our company continues to have an interest in pursuing 25, 30 percent cost-share relationships in this area into a market that,

[illegible] AVAILABLE

while it does not yet exist, we believe will be real and is in the national interest. I would appeal for some support in this regard over the next 4 years. We have cperated in 1985 at a level of about $300,000 support, at which level it is virtually impossible to keep a team together.

And if I might, Mr. Packard, I will advance a forward question, that if funding was totally discontinued in this area, the majority of parallel research effort would continue. We do invest about 2.2 percent of our sales dollars in our direct research engineering programs, but there is a significant area of the activity directed to higher energy density and an improvement in cycle life that we could not support solely on our own.

An alternate advanced system which I wanted to touch on this morning is the zinc-bromine recyclable battery. In principle it has a capability potential in the area of 70 to 80 watt-hours per kilogram, in comparison with 56 to 60 for the advanced lead-acid system. We believe that a 1,000-cycle capability is real. The system operates basically with low-cost materials—plastics, carbon impregnations, aqueous systems—that are fairly easy to contain, and we do not think that the problems of this system are insuperable.

I must say the batteries look a little strange. The chemicals are contained within the electrolyte materials, and while this pictorial is a wee bit complicated, the flow of electrolyte runs between alternate parallel plastic and separator matrices within a frame structure such that we move the two electrolytes in different directions and are able to generate significant electrical energy from the result.

This is a typical electrode. It consists of a duel molding of a polypropolene base material with a carbon plastic second injection system. It is a parallel part to that old lead combo grid that I showed you a few minutes ago.

This is a small module of such a battery. This is a small 12-volt unit, and while very honestly it sits on a lab bench and doesn't appear capable of doing anything at all—our own management really wasn't very convinced, either—but that small unit we simply packaged on a minitrailer behind one of these small Sinclair things, and the zinc-bromine system successfully pushed it around at 15 miles an hour or better, just to let our people know that, "Hey, sure we're in the battery business, but this one is a different one and it can be made to work."

We are in partnership on a world basis. Our corporation bought rights to the Exxon activity which has generated, with our own work, in excess of $12 million of R&D in development of the zinc-bromine system. At the present time we are in partnership with Toyota in the Far East; SEA, which is an Austrian company largely funded by the Austrian Government; and a company called Sherwood Overseas in Australia.

Each of the partners, with minor continued support from Exxon Corp., does independent research and development but shares their activities on a monthly basis and meets twice a year to study one another's data. Toyota is fairly keen, and intends to have three vehicles on the road in 1987. We have offered down the road to not only share our technology but also manufacture, if an when that capability comes onshore.

At the present time the investment that has happened is of the order of this, and I might say that in the last 12 months it is the only one of the advanced systems that physically has been assembled and used in the dynamometer testing at Ford in Detroit to power the ETX unit. This battery is currently on test in our labs, but a little closer view: This is the battery that achieved a range a little in excess of 80 miles on one of the Ford test vehicles in the ETX Program there. This was dynamometer testing, not road testing. This battery is currently on continuation of cycle life testing in Milwaukee.

We believe that, given some support, we have the potential of demonstrating 70 percent round-trip efficiency, better than 1,000 deep cycles, and a cost of less than $55 per kilowatt hour, which is pretty strong in relation to advanced battery systems.

We believe that there is a need to overcome very significant problems so far revealed in the early research. Electrode warpage is a major one. The chemistry of the electrolyte system is another one, and the potential for leakage in this battery is a very significant problem.

We see a need for some support in a program that would be of the order of not less than 3 to 4 years, that would give us a capability to demonstrate a mnaufacturing potential for vehicles driven by such a system. We believe that a program of significance would be of the order of $1 to $1.25 million.

Our company is willing to cost-share within this kind of a program. We don't believe that a total abandonment of support would result in the American battery system being able to continue alone. We see this product as one having no current market position here. We see it as a necessary follow-on, but our position as a corporation is that the development may be deferred very significantly unless we can get some form of continuing support.

Private industry cannot go on this one alone. We believe that at funding less than three quarters of a million dollars a year, it is unlikely that this program should be supported or can be supported. And within our own corporation, while we very much would like to continue work on it, the battery industry at this point is not sufficiently prosperous to be able to take all the high-risk activities alone.

Thank you for your time.

[The prepared statement of Dr. Halsall follows:]

The DOE Transportation Program and its FY 87 Budget

Presented to the
Subcommittee on Transportation, Aviation and Materials
Committee on Science and Technology
U.S. House of Representatives

by
Vincent M. Halsall
Vice President
Battery Division, Johnson Controls, Inc.

February 27, 1986

I wish to thank the Subcommittee on Transportation, Aviation and Materials for this opportunity to present our views on the Department of Energy's Electric Vehicle Research and Development Program, and, specifically, on the progress and outlook for the most critical component of an electric vehicle, the battery.

For background purposes it is important to note that Johnson Controls is the largest manufacturer of automotive batteries in the world. I say in the world because, although we only serve the U.S. market with batteries, the volume we produce exceeds that of any company serving the total world market. The fact that the U.S. automotive battery market is 50% greater than that of Western Europe, despite its population exceeding ours by 50%, gives some perspective to this nation's commitment to and dependence on personal transportation.

The relationship between American consumers and their personal vehicles is, as you know, an exceedingly strong one. Within the past decade American consumers have shown that their desire to drive and purchase vehicles of their choice supercedes threats to the well-being of our domestic economy.

When foreign pressures drove the price of gasoline to historical highs, the American people still consumed millions of barrels of oil to preserve their lifestyle. It wasn't so much a matter of choice as it was a result of necessity because personal vehicles are an integral part of American transportation.

If we look at the imports' nearly 25% share of car sales, and the Motor Vehicle Manufacturers Association estimate that over 500,000 jobs have been lost in our automotive and supplier industry since 1978, clearly we see that domestic economic concerns take a backseat when consumers go to automotive showrooms.

This very recent and sobering history should give new meaning to deliberations on whether the U.S. should be committed to an electric vehicle research and development program. Are electric vehicles a viable transportation option for the American people? Various studies have shown they are. Would their use minimize U.S. dependency on foreign sources of energy? By a substantial margin. Should the required technology be available within our country? Absolutely.

To remain in the lead in electric vehicle battery development the U.S. needs to provide economic incentives to U.S. companies. These incentives are critical to counteract all of the negatives associated with private investment such as lack of a predictable, much less existing, market and strong competition from established products for limited corporate research and development funds. Government support is also required to allow us to work on an equal basis with international competitors.

Advanced battery development at Johnson Controls has concentrated on the two systems, lead-acid and zinc-bromine, which we believe are the most promising candidates for a commercial electric vehicle battery.

The advanced lead-acid system has the best track record of any energy storage system being considered. It is low cost, has high energy efficiency, is recyclable, has a proven manufacturing system and has ample field experience. Importantly, it has also shown the greatest improvements toward the performance, life and cost goals of the electric vehicle program. DOE and private industry support of nearly 160,000 hours of development has resulted in a 60% improvement in specific energy and a doubling of cycle life of the lead-acid battery. As a result, we exceeded the performance goals set for the "Improved State of the Art" program.

Advanced program goals consist of achieving a specific energy of 56 watt-hours per kilogram and demonstrating a deep discharge cycle life in excess of 800 cycles. We believe that these goals are technologically attainable.

The primary opportunity for improved specific energy is in the development of the concept of a forced flow of electrolyte through porous electrodes. This project would consist of developing crack-free porous lead electrodes with highly uniform electrolyte permeability and long-term structural integrity; process developments to ensure leak-free electrode seals; and design of an efficient cell with supporting subsystems to accomplish the forced flow of electrolyte. This forced flow concept is also being developed in W. Germany.

Cycle life improvements can be achieved by reducing losses of active material integrity and positive grid corrosion. Work on these problems will involve modifying the morphology of the active material, developing improved means of physical support of the positive active materials and developing improved grid alloys.

To be candid, less than a desired level of progress has been made on these developmental areas within the past year. The reason is economic, not technical. Minimal and unpredictable levels of federal support, coupled with the lack of commercial applicability for this work, provide scant justification for our company to sustain funding aimed at meeting the advanced goals.

We estimate that the goals can be achieved over a four-year period of coordinated research and development engineering. The total funding level required, including privately sourced cost-sharing, needs to average $800,000 to $1,000,000 per year. A higher funding level will not significantly accelerate the program; lower funding levels will disproportionately extend the program. Let me stress that the lead-acid system represents the best investment available for an electric vehicle battery.

In addition to the lead-acid system, the zinc-bromine battery offers significant potential to cost-effectively and technically meet the requirements of electric vehicle applications. Zinc-bromine is the only one of the so-called "advanced" systems that is cost-effective both in terms of initial and life cycle costs, whose technical feasibility can be demonstrated and which can claim significant technical progress. In addition to these features, advantages to zinc-bromine are its ability to operate in ambient temperatures, low projected manufacturing costs, minimal maintenance and its compatibility with regenerative braking.

Over $10 million and 120,000 hours have been spent by Exxon Research and Engineering and Johnson Controls on development of the zinc-bromine system. As part of this activity Exxon has been granted over 25 patents covering features of battery design and operation. Substantial development efforts are ongoing in Japan, Europe and Australia. We believe that their results would be available to any continuing program of ours.

Our goals for the zinc-bromine program are to demonstrate consistent battery life in excess of 1,000 deep discharge cycles; to demonstrate a complete battery that has a specific energy of at least 70 watt-hours per kilogram and a specific power of at least 120 watts per kilogram; to achieve an energy efficiency of over 70%; and, to achieve an estimated mass production manufacturing cost of less than $55 per kilowatt-hour. The ultimate goal, of course, is to deliver a complete, full-sized electric vehicle battery capable of meeting the aforementioned objectives.

Progress to date has reinforced our belief in the feasibility of meeting these goals. Long life has been demonstrated by the achievement of over 1,000 deep discharge cycles by a small Exxon battery on test at Sandia National Laboratories. Electrolyte has been subjected to over 1,400 cycles without evidence of degradation. In addition, we accomplished the operation of a parallel large cell stack. And, it is important to note, a zinc-bromine system has successfully powered an experimental vehicle during dynamometer testing.

We have also clearly identified further development needs that can be satisfied in a timely and cost-effective manner. We can address the problem of electrode warpage and shorting, which inhibits cycle life and reliability, by developing bromine resistant electrode materials, design refinements and improved construction techniques. Self discharging characteristics, which reduce energy efficiency, can be ameliorated through optimized separators, electrolyte additives and by minimizing or eliminating electrolyte crossflow, shutdown losses and bromine retention by the activation layers. Finally, specific energy and power can be increased through various improvements in the battery's component and system design as well as component performance.

We believe that three to four years of coordinated development, engineering and research effort can lead to demonstration of complete, full-size zinc-bromine batteries that meet our program goals. The total funding level, including privately-sourced cost-sharing money, needed to accomplish these goals is $1.2 to $1.5 million per year. As is the case with lead-acid system development, a higher funding level will not significantly accelerate the program, nor will a lower level allow us to move forward in a productive manner. I should also note that delays in receiving funds, such as we are currently experiencing with FY 1986 appropriations for zinc-bromine, are extremely disruptive to development schedules.

In conclusion, Johnson Controls strongly supports the U.S. taking an active role in assisting private industry in developing battery systems for electric vehicles. The two most promising battery systems are advanced lead-acid and zinc-bromine. As an active observer and participant in worldwide battery development, we are very much aware that our country's leadership position in this technology is being diminished. We should not allow our reliance on personal transportation to further increase our vulnerability to foreign economic interests.

Thank you for giving these views your sincere consideration.

February 27, 1986

BIOGRAPHY

VINCENT L. HALSALL, born December 12, 1931 in United Kingdom

Became U.S. Citizen 1969

Education

Associate of the Royal Institute of Chemistry - London, England, 1955
Fellow of the Royal Institute of Chemistry - London, England, 1962

Positions at Johnson Controls, Inc.

Joined Johnson Controls in 1964
Senior Development Engineer, Battery Division, 1964
Manager, Product Engineering, Battery Division, 1967
Manager, Engineering Operations, Battery Division, 1972
Vice President, Engineering, Battery Division, 1973

Work Experience

Chloride Electric Storage Co., England - Battery Research
Hart Battery Co., Ltd., Quebec, Canada
Electric Storage Battery Co., Ltd., Ontario, Canada

Professional Activities

Chairman Battery Council International Technical Committee
Society of Automotive Engineers
Institute of Chemical Engineers
Royal Institute of Chemistry

Author/co-author of nine patents relating to batteries.
Author/co-author of many published papers.

AVAILABLE

VISUAL AIDS

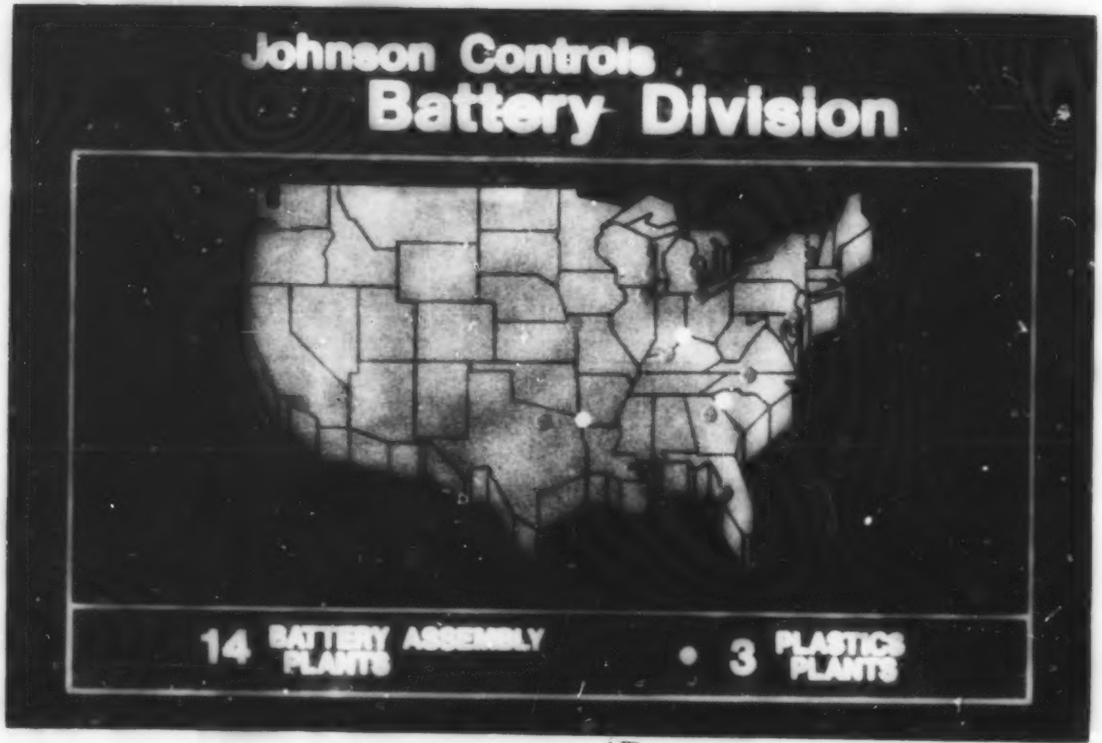
JOHNSON CONTROLS

JOHNSON CONTROLS, INC.

- Four business segments:
  - Batteries
  - Controls
  - Automotive Components
  - Plastics
- 29,000 employees
- 1985 sales were 1.8 billion

BATTERY DIVISION

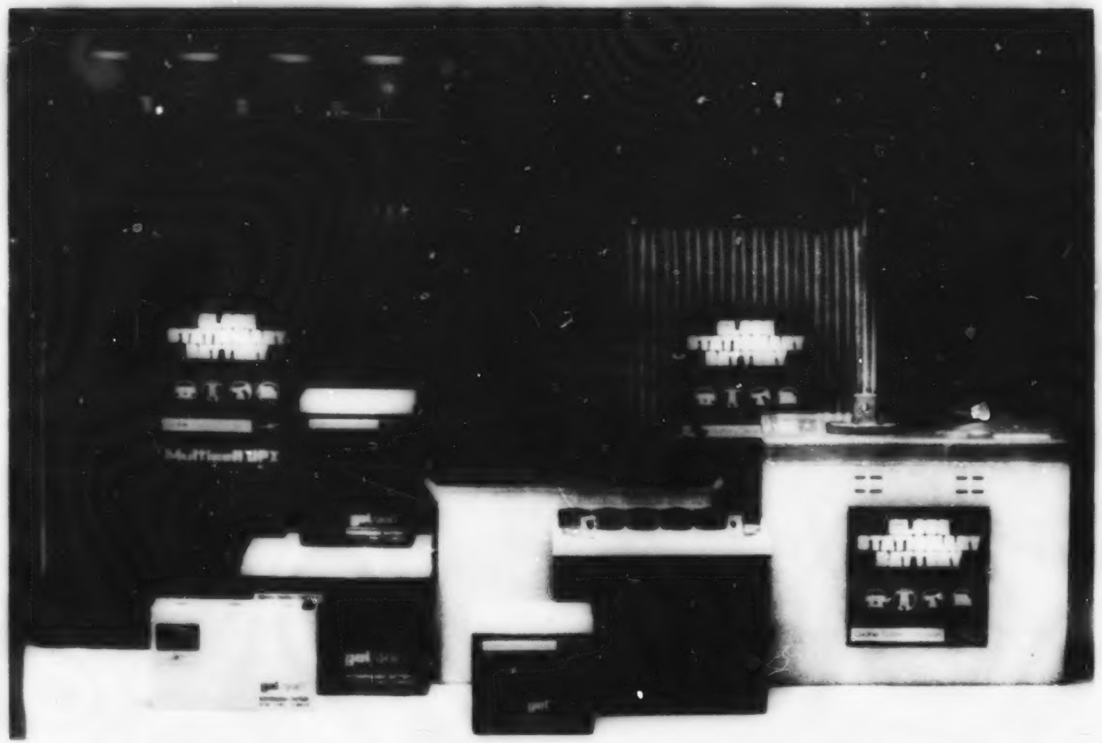
- WORLD'S LARGEST MANUFACTURER OF AUTOMOTIVE AND COMMERICAL VEHICLE BATTERIES
- MANUFACTURES INDUSTRIAL, STATIONARY, AND SPECIAL APPLICATION BATTERIES
- 17 DOMESTIC MANUFACTURING PLANTS
- LICENSES TECHNOLOGY WORLDWIDE

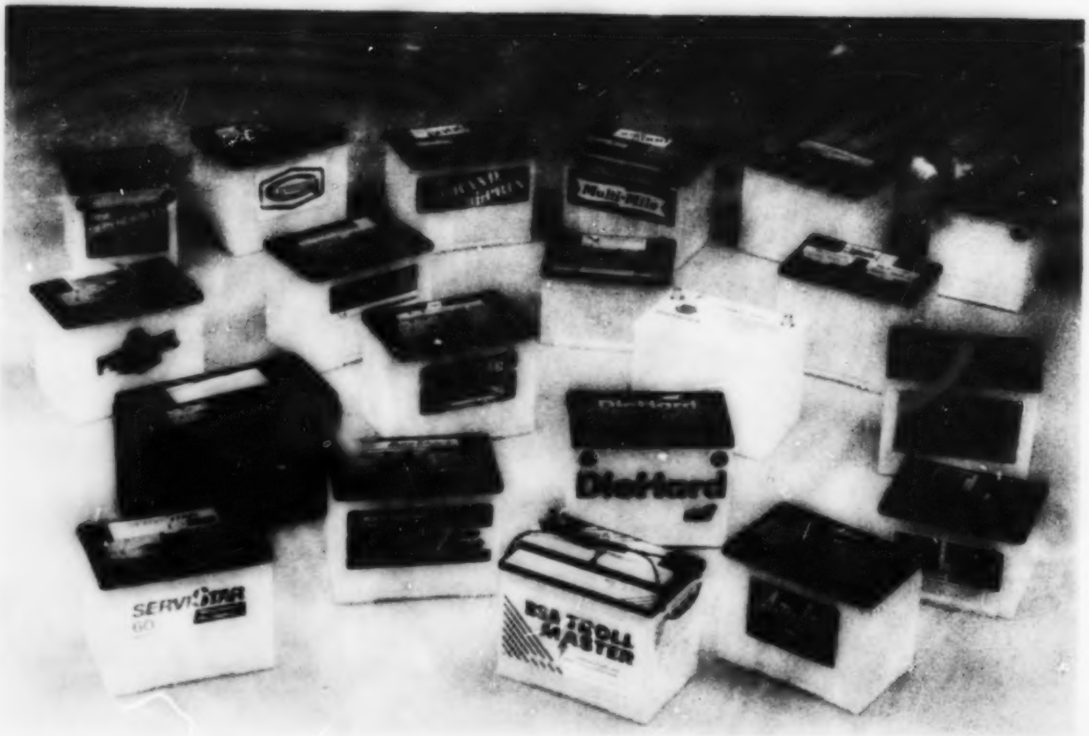


Johnson Controls
Battery Division

14 BATTERY ASSEMBLY PLANTS

● 3 PLASTICS PLANTS


GLOBE STATIONARY BATTERY
GLOBE STATIONARY BATTERY
GLOBE STATIONARY BATTERY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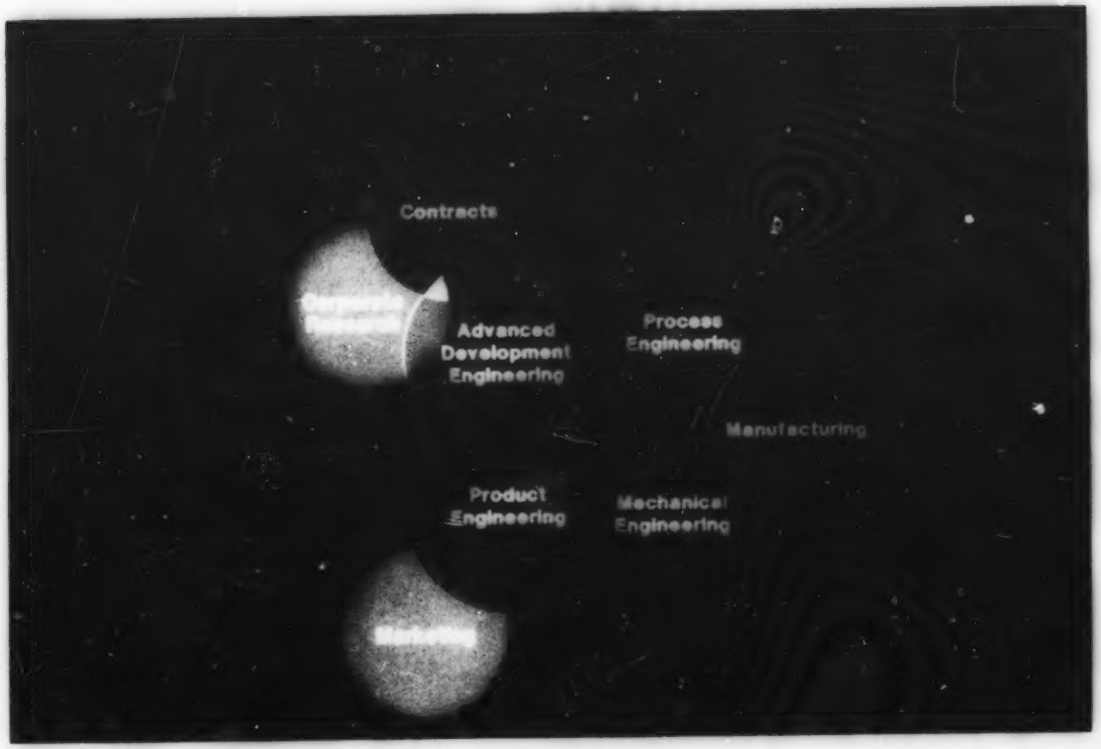
DieHard
DieHard
SERVISTAR
60
MASTER



Contracts

Corporate Research

Advanced Development Engineering

Process Engineering

Manufacturing

Product Engineering

Mechanical Engineering

Marketing

LEAD-ACID

LEAD-ACID ADVANTAGES FOR ELECTRIC VEHICLES

- A PROVEN COMMERCIAL SYSTEM WITH INDUSTRY IN PLACE
- LOW COST
- HIGH ENERGY EFFICIENCY
- GREATEST DEMONSTRATED RECENT IMPROVEMENT IN PERFORMANCE
- EASILY RECYCLABLE
- MOST FIELD EXPERIENCE

LEAD-ACID PROGRAM BACKGROUND

- 160,000 RESEARCH AND ENGINEERING MAN-HOURS HAVE BEEN EXPENDED OVER EIGHT YEARS
- SPECIFIC ENERGY IMPROVEMENT OF 60% ACHIEVED - POTENTIAL FOR 100%
- CYCLE LIFE DOUBLED
- WORK WOULD NOT HAVE BEEN DONE WITHOUT DOE SUPPORT

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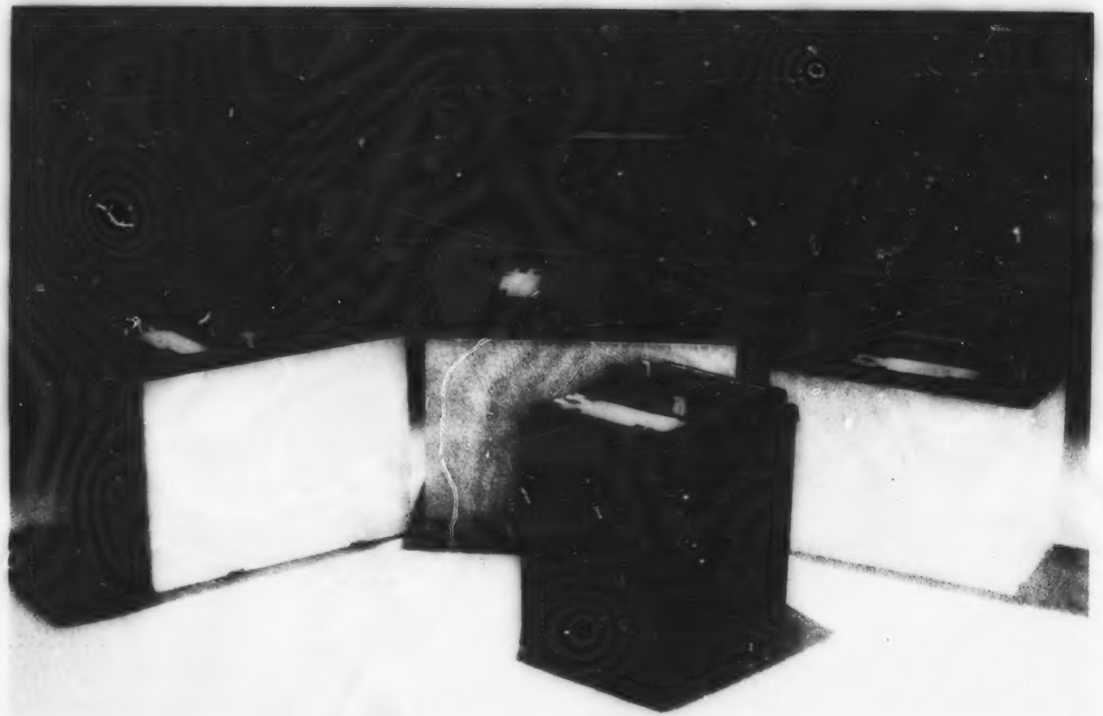

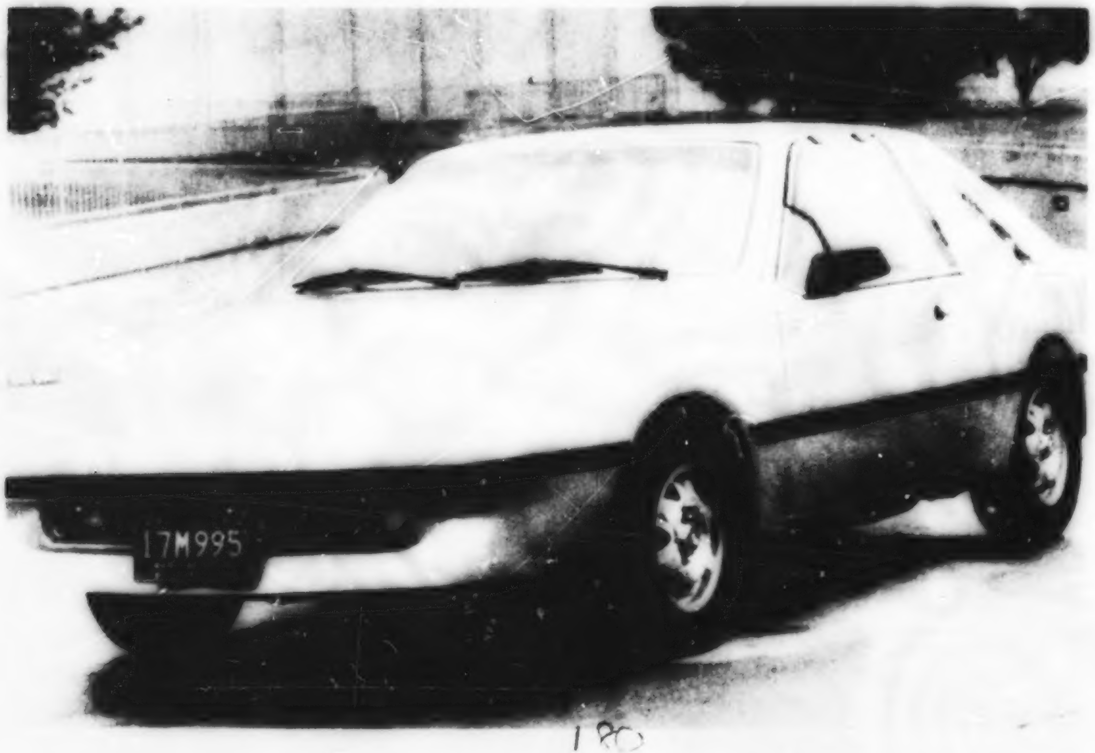
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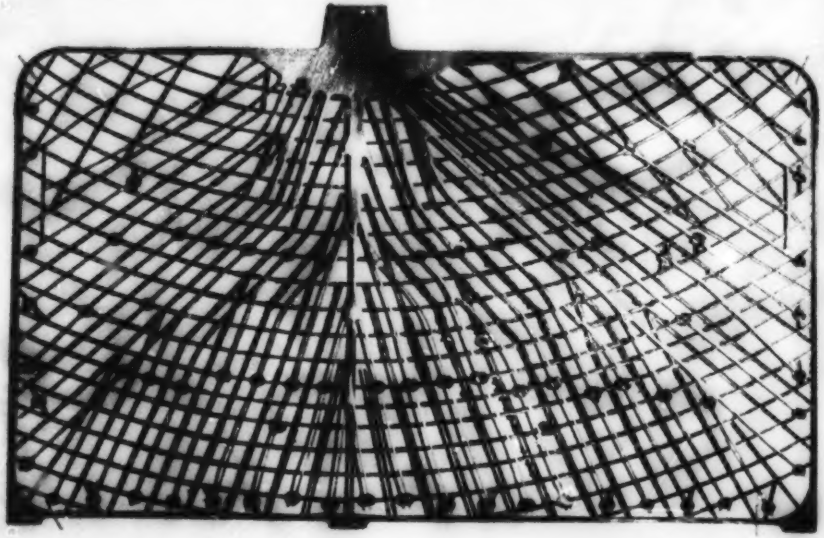
LEAD-ACID EV BATTERY PROGRAM OBJECTIVES

- SPECIFIC ENERGY 56 WATT-HOURS PER KILOGRAM
- DEEP DISCHARGE CYCLE LIFE OF 800+ CYCLES
- DELIVER ELECTRIC VEHICLE BATTERIES TO DEMONSTRATE HAVING MET THESE GOALS

LEAD-ACID EV BATTERY R & D NEEDS

- DEVELOP A PRACTICAL, LOW COST FLOW-THROUGH BATTERY DESIGN
- IMPROVE THE STRENGTH, UNIFORMITY, AND PHYSICAL SUPPORT OF THE ACTIVE MATERIALS
- IMPROVE THE CORROSION RESISTANCE AND CONDUCTIVITY OF THE ELECTRODE CURRENT COLLECTORS

COMBO POSITIVE
BRANCHED RADIALS



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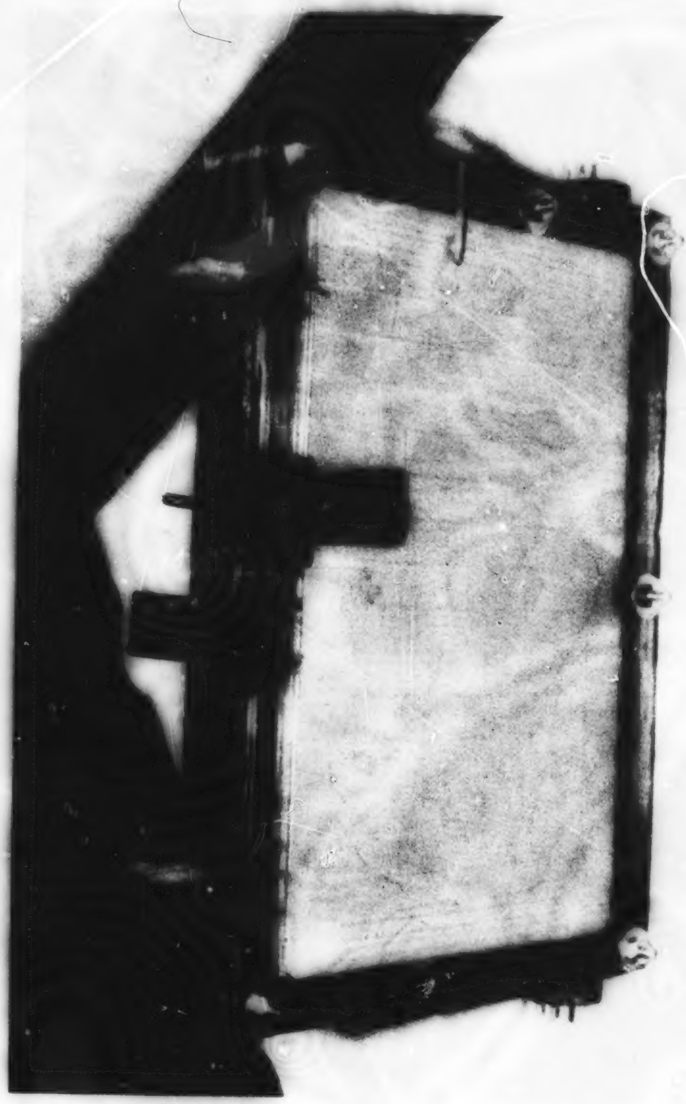

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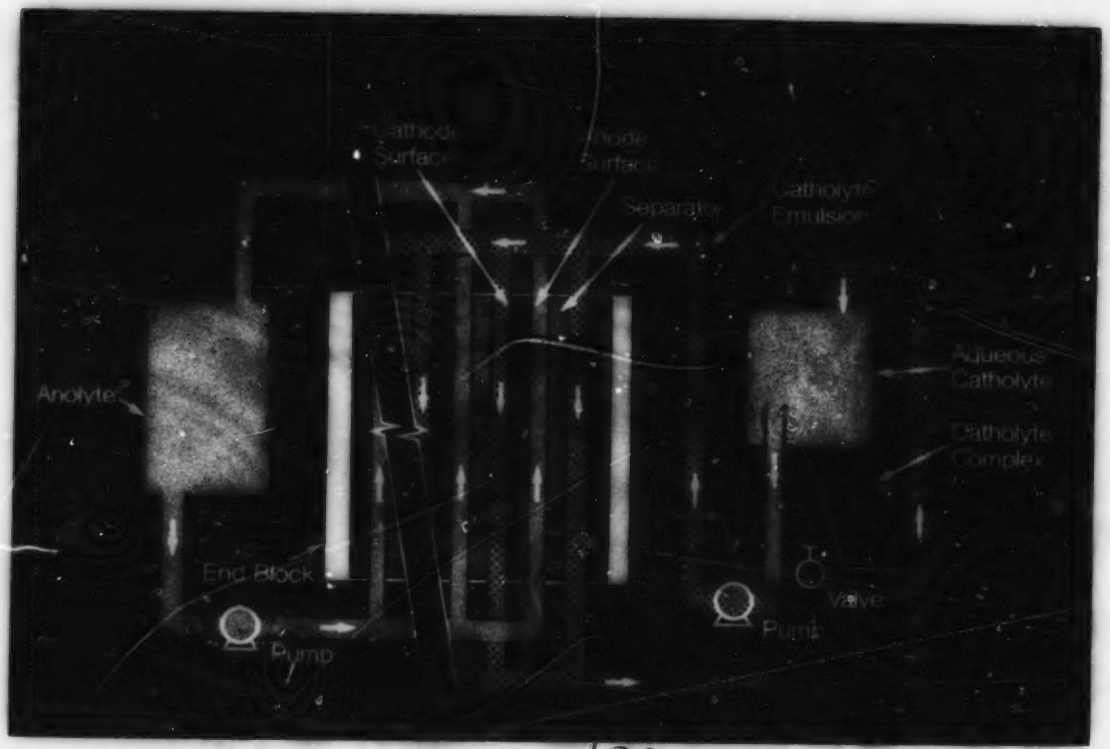
LEAD-ACID EV BATTERY PROGRAM REQUIREMENTS

- AT LEAST FOURS OF RESEARCH AND ENGINEERING
- AN AVERAGE TOTAL FUNDING LEVEL (WITH JCI COST SHARE) OF 0.8 TO 1.0 MILLION DOLLARS PER YEAR

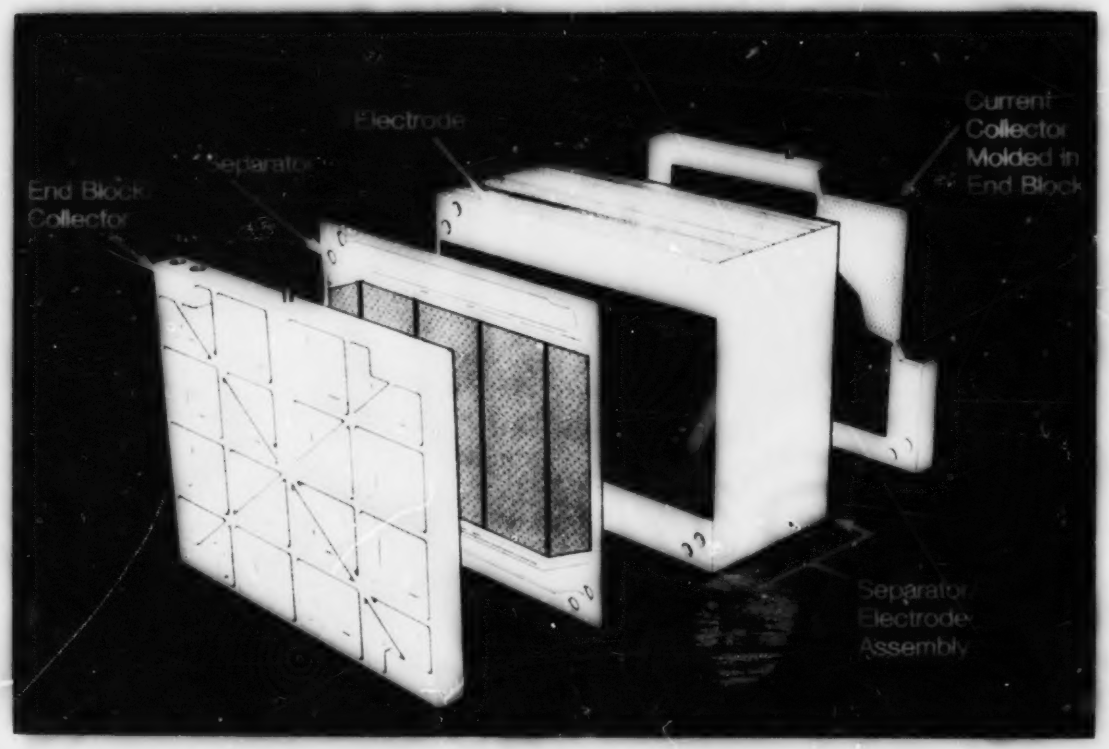
ZINC-BROMINE

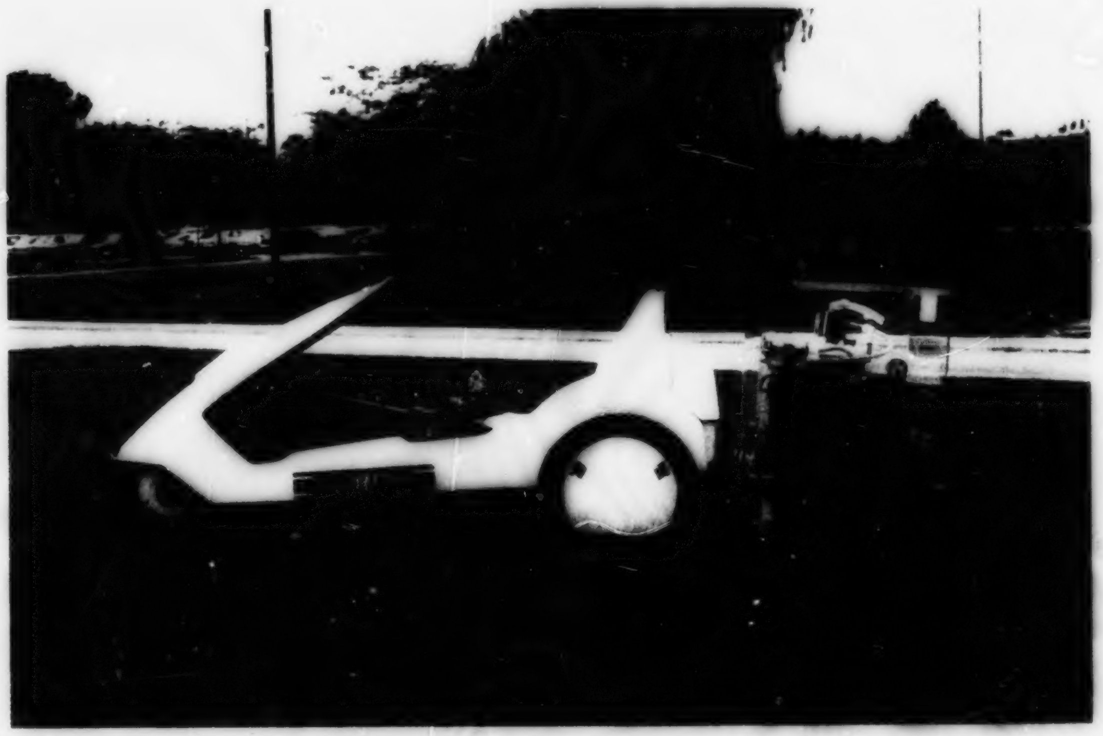
ZINC-BROMINE ADVANTAGES FOR ELECTRIC VEHICLES

- POTENTIAL SPECIFIC ENERGY OF 70 TO 80 WH/KG
- AMBIENT TEMPERATURE OPERATION
- POTENTIAL DEEP CYCLE LIFE GREATER THAN 1,000
- LOW PROJECTED MANUFACTURING COST


Cathode Surface
Anode Surface
Separator
Catholyte Emulsion
Anolyte
Aqueous Catholyte
Catholyte Complex
End Block
Pump
Valve
Pump

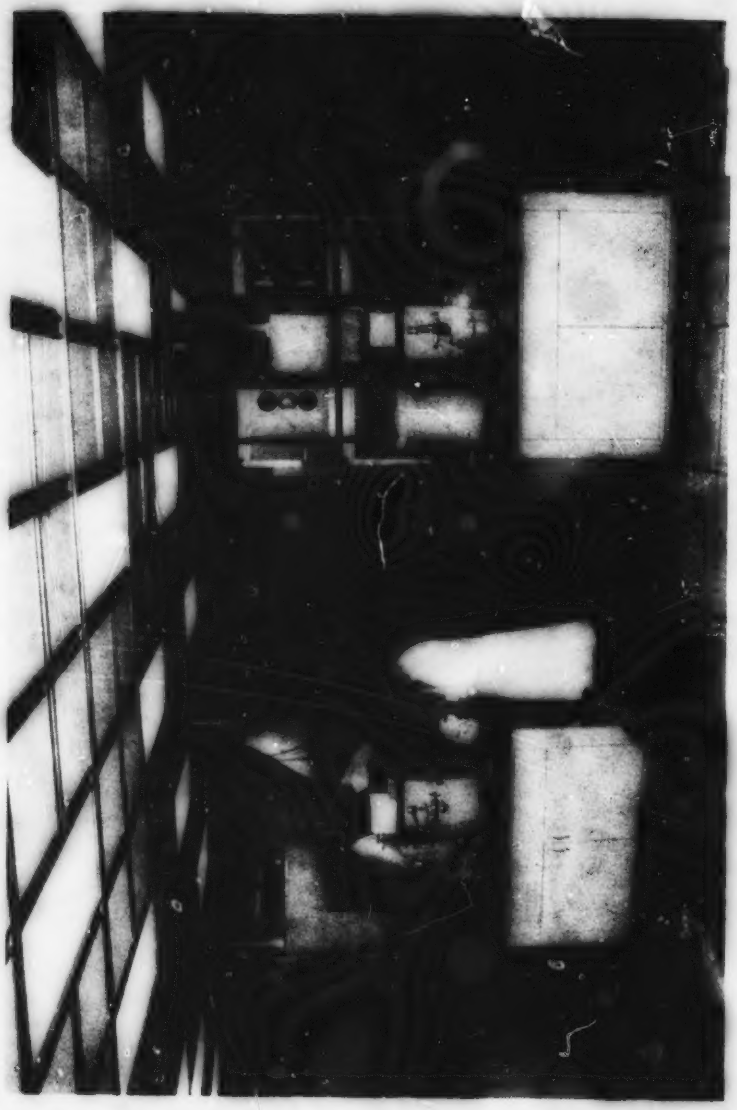
190

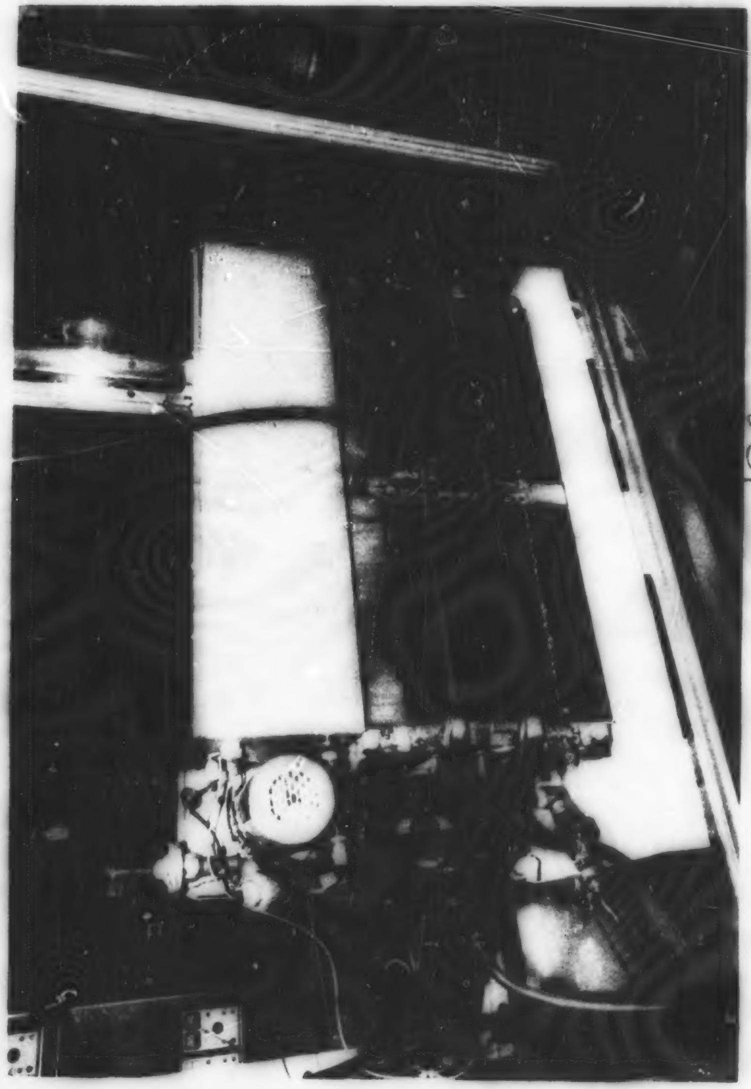

Electrode
Separator
End Block
Collector
Current
Collector
Molded in
End Block
Separator/
Electrode
Assembly



ZINC-BROMINE PROGRAM BACKGROUND

- 120,000 MAN-HOURS AND 10 MILLION DOLLARS OF PRIVATE FUNDING SPENT OVER 13 YEARS BY ERE AND JCI
- OVER 1,200 CYCLES DEMONSTRATED
- ONLY ADVANCED SYSTEM TO POWER A VEHICLE IN THE LAST YEAR
- CONTINUOUS PROGRESS MADE IN DEVELOPMENT EFFORTS





NEED FOR GOVERNMENT SUPPORT

- DIVERSIFICATION OF OUR ENERGY BASE IS STRONGLY IN THE NATIONAL INTEREST
- BATTERIES ARE THE MOST CRITICAL PERFORMANCE RELATED ELECTRIC VEHICLE COMPONENT
- BATTERY DEVELOPMENT CAN TAKE 10 TO 20 YEARS WHILE PETROLEUM SHORTAGES CAN OCCUR IN LESS THAN ONE
- THERE IS NO INCENTIVE FOR PRIVATE INDUSTRY TO DEVELOP ELECTRIC VEHICLE BATTERIES SINCE THERE IS NO EXISTING OR ACCURATELY PREDICTABLE MARKET
- WITHOUT GOVERNMENT CONTRIBUTIONS TO THE COSTS, ZINC-BROMINE AND LEAD-ACID ELECTRIC VEHICLE BATTERY DEVELOPMENT WORK WILL CEASE

ZINC-BROMINE EV BATTERY PROGRAM OBJECTIVES

- LIFE IN EXCESS OF 1,000 DEEP DISCHARGE CYCLES
- ENERGY EFFICIENCY OF 70%
- SPECIFIC ENERGY OF 700 WATT-HOURS PER KILOGRAM AND SPECIFIC POWER OF 120 WATTS PER KILOGRAM
- COST OF LESS THAN $55 PER KILOWATT-HOUR

ZINC-BROMINE EV BATTERY R & D NEEDS

- DESIGN FOR MAXIMUM SPECIFIC ENERGY AND POWER
- IMPROVE ELECTRODE AND SEPARATOR MATERIALS TO INCREASE ENERGY EFFICIENCY AND LIFE
- DEVELOP ASSEMBLY TECHNIQUES TO ASSURE LOW COST AND RELIABILITY

ZINC-BROMINE EV BATTERY PROGRAM REQUIREMENTS

- THREE TO FOUR YEARS OF ENGINEERING AND RESEARCH EFFORTS
- AVERAGE TOTAL FUNDING LEVEL (INCLUDING JCI COST SHARE) OF 1.2 TO 1.5 MILLION DOLLARS PER YEAR

ZINC-BROMINE PARTNERSHIP

- Exxon Research and Engineering Co. developed the basic technology
- Johnson Controls, Inc. is working on design optimization for the electric vehicle application as well as materials and process development
- Toyota Motor Corp. of Japan is concentrating on battery design and battery/vehicle interfaces - plan to have several zinc-bromine vehicles on test in 1988
- S.E.A. of Austria is working on product design and process development - they have just installed a zinc-bromine battery in a Volkswagon electric vehicle
- Sherwood Overseas Co. of Australia is concentrating its efforts on process development

Mr. **Packard**. Thank you. Dr. Halsall.

Dr. Tennery.

STATEMENT OF DR. VICTOR J. TENNERY, DIRECTOR, HIGH TEMPERATURE MATERIALS LABORATORY, OAK RIDGE NATIONAL LABORATORY

Dr. **Tennery**. Thank you, Mr. Chairman, other members of the committee and staff.

I would like to take a few minutes this morning to review for you the status of the High Temperature Materials Laboratory [HTML], which this subcommittee has been instrumental in the authorization process. I'll bring you up to date on that and I'll particularly address three topics which were cited in the invitation letter: I will cover the current progress of the construction of this new laboratory at Oak Ridge National Laboratory; I will discuss the plans for the operation of the HTML and its facilities, and what those facilities are; and, third, the proposed research thrust in the area of high-temperature materials that we intend to carry out internally in the HTML.

First, I would like to briefly cover the history of the HTML, to give you a perspective of how long it takes for a facility like this to come into being in the system that we presently operate in. In 1977 the original concept for the HTML occurred as a result of discussions amongst research staff as the Oak Ridge National Laboratory, as an outgrowth of a series of workshops that were carried out by what now is the Material Sciences Division of the Office of Basic Energy Sciences in DOE, to identify critical materials needs for the United States.

One of the high priority items that was identified as an outgrowth of these workshops was in the area of high-temperature materials, and the final outgrowth of that was the idea that a laboratory specifically designed and organized and operated to focus on research in this area was an important matter.

Furthermore, in 1980 an HTML industrial users committee was formed at ORNL to assist us in identifying how such a laboratory could best be operated to perform important high-temperature materials research and, importantly, how such a laboratory at a national laboratory could interact most effectively with U.S. industry. This group included five high-level industrial research managers and was chaired by Mr. Bill Manly, who was then executive vice president of Cabot Corp.

The fiscal year 1986 appropriation of $2.57 million approximately completed funding for this construction project, and on May 17 of this year we had an inauguration ceremony and will shortly be planning a proper dedication ceremony for this new facility. I look forward to inviting the subcommittee to attend that ceremony.

I will now cover the current progress of the construction, and I am happy to report that the construction project is proceeding very well. The building is basically a 64,500 square foot, two-story laboratory which has been designed to be particularly stiff, in order to not impair delicate experiments and instruments that will be used in the technical work in the lab.

The construction started on January 25, 1985, and the formal completion date for the construction contract is February 15, 1987. A drawing of the HTML by the architect is shown in figure 1 of my testimony, and a photo of the building on February 14th of this month is shown in figure 2. You can note the correlation between the photograph and the drawing, and I am glad to report they are very similar. As of February 12 the building was 50 percent completed and is on schedule, and our construction contractor is very optimistic that the building perhaps can be completed prior to the officially planned completion date.

I would like to now cover an issue that was brought up in the invitation letter: the high-temperature materials thrust areas for the HTML. In the interest of time I will not replay the tune that you have heard, that we have all heard here this morning, to the extent that I was originally planning, which is the aspect of ceramic technology and what it might mean in the future relative to the gross national product and other economic and technological issues relevant to the United States versus foreign competition.

However, based on this intense interest and emphasis in structural ceramics in both this country and abroad, we have made the concerted decision that the particular research groups in the ORNL organization that will be located in the HTML will be three research groups whose principal focus is structural ceramics, and in a few moments I will delineate some of that work that is ongoing at the present time. We decided to do that so that interdisciplinary interaction between these groups will be enhanced, and that those groups will be readily located in this new facility to also enhance interactions with outside users I willk also dwell on in just a moment.

I would like to delineate and take a couple of minutes to talk about an issue that has been talked here this morning in various ways, and this is the question of what is it about these ceramic materials that makes them different than alloys, and what is it about these ceramic materials that makes the achievement of reliability so difficult? Is it a matter of not knowing the science or is it a matter of not knowing how to do good engineering to apply the science? I personally feel that it's a combination of those two matters. I don't believe all the science is in hand, unfortunately.

I would like to read, if I could, directly out of the testimony for a short period.

The properties, and particularly the mechanical properties, of a ceramic body are intimately connected to the processing required to transform the starting materials into a dense ceramic material. Due to the fact that these ceramic materials are inherently brittle relative to metallic alloys, their mechanical properties are very sensitive to microstructural features on a scale of a few nanometers.

The science and technology of controlling the microstructure uniformity of structural ceramics is the key objective of all the international efforts now underway in this area. We have heard that referenced to this morning. For example, the Advanced Materials Development Program in Transportation/Conservation of DOE is organized and planned to find the solution to this problem in a number of ceramic systems. My opinion is that the fiscal year 1987 budget value that has been recommended will significantly slow progress toward attainment of that objective in the systems being pursued in that program.

The major technical goal of the Advanced Materials Development Program—the research that will be done in the HTML, the research being done in U.S. industry and in programs in other countries—is to learn how to achieve and control that microstructure uniformity, and that is absolutely crucial if these variations we have heard about this morning are to be prevented, and so the solution to that problem is crucial to the economic viability of these materials, even if their properties theoretically are acceptable.

The technology goal, the major technology goal is the knowledge, finding the knowledge of how to identify and control all of these variables that will consistently and economically produce the required microstructure. The features, the so-called flaws that cause the problems, are on a very fine scale. As was commented earlier, there are techniques that have been demonstrated in a laboratory that can find flaws of the order of 20 to 25 micrometers in extent. Unfortunately, these techniques cannot presently do that rapidly and economically, and that will be absolutely necessary in the future.

To illustrate the point of how we see the future ceramic processing requirements to evolve, I will refer to figure 3 in my testimony which shows, as an example, a ceramic processing flow sheet of the future for the technique called slip casting for fabricating complex ceramic parts. The process flow is shown as dotted lines in this diagram, and other operations identified as "characterization" are shown within ovals in these flow sheets. Unfortunately, the identification of the key processes that are required in these characterization steps are still in their infancy and it is only, as I see it, through the Federal Government's support that the identification of these measurements and how to implement them rapidly and economically will occur.

In the ceramic production process of the future, process control will be maintained based upon the results of these kinds of measurements shown in this diagram, in the ovals, and feedback control will be required, as shown in my diagram by heavy lines to the major process operations which are in the boxes. Present ceramic manufacturing processes are far removed, in my opinion, from this sophisticated feedback manufacturing engineering approach.

Relevant to the HTML, we have selected the research instruments for purchase and for putting into this new laboratory with these needs clearly in mind. These are research instruments, and we intend that they will be used in work both in DOE programs and with outside industrial and university users, to help advance the knowledge and requirements for these characterization processes that will be required in ceramic manufacturing of the future.

We have devoted significant time and energy to the issue of how the HTML could best be operated to maximize its utilization, not just as a laboratory to be used at ORNL for ORNL researchers, but by the industrial and university communities. We feel that we have proposed and are planning to operate the laboratory in a way that that can be done most effectively. We would like to see advanced graduate students in materials science, and engineering utilize this laboratory for particularly advanced dissertation research. We perceive that many university departments are having a growing problem with buying the complicated and sophisticated instruments necessary to properly train their advanced graduate students.

With this in mind, we have adopted a user center concept for the HTML which basically has the following components. The instruments that we will buy and are buying as part of this appropriation will be located in four user centers in the laboratory. They are identified as a materials analysis center, an x-ray diffraction center, a physical properties center, and a mechanical properties center.

These instruments have been purchased with the idea of as much as possible having them computer-controlled, so that users who are not as familiar with an instrument as they might be can come in with minimum training and apply the instruments to their particular needs. We are planning at the present to provide user access to these centers at no cost when the collaborative research results in public information, and this policy is consistent with present ORNL user center policy and DOE policy.

Procurement of these research instruments is well in progress. We have developed a prioritized list of the needed equipment items, and we are in the process of acquiring at the present time a total of 15 major items. The first two instruments are a 400 kilovolt analytical electron microscope and a high spatial resolution Auger spectrometer system. I might say that the bids that have been received, very strong competitors in both of those bid packages are from Japan. I presume you may get tired of that theme, but that is the case. The specification preparation for eight additional instruments is also well underway.

To provide a convenient and efficient access to these centers, particularly for outside users—that is, users from outside ORNL—we have argued that we must have a dedicated staff to operate and maintain these sophisticated instruments. We are submitting a budget request starting in fiscal year 1987 to the Office of Basic Energy Sciences for this purposes, at the recommendation of DOE. It is absolutely essential for the future operation of these centers that we do have support for this small staff.

We have had contracts with many industrial firms relevant to our ideas of how these centers would best operate in their view, and we have had contracts form roughtly 50 industrial firms, and we have now contacted these people for their suggestions on specifically how such centers could best operate.

I would like to now say a few words about some initial user center activities. With support from Industrial Transportation—I'm sorry—Transportation/Conservation in DOE, with some funding from that organization this year, we have instituted two preliminary efforts to see how best to operate with industrial researchers.

One of these collaborative efforts is in fact with Allison Gas Turbine, and it involves the characterization of a domestic silicon nitride ceramic which we have heard some words about this morning, which was initially a candidate for use in the AGT 100 rotor. Serious problems with static fatigue were identified in this ceramic, and it was not clearly determined until we started this work as to exactly why this figure process occurred or what its basic origin was.

In a period of about 3 months we have determined, by using high-resolution transmission electron microscopy and some other techniques, that fatigue in this material which is unacceptable in regard to considering the material for use as the turbine rotor is due to a very specific oxidation process in the secondary grain boundary phase in this ceramic, and it occurs only when the tensile stress is present, and this oxidation occurs as very small, microscopic voids in the secondary phase. We think this is an example of the kind of work that may point the way to better understanding and microstructural improvements in these ceramics that will be required in the future.

We have a second activity with Cummins Engine Co. which is just getting underway, that is described in the testimony.

We have a series of research efforts now underway in the three research groups that will be located in the HTML. I have indicated in the testimony in figure 4 where they will be located, and we will be moving them into the laboratory in about 6 months, it appears at the present time.

We also have an outside advisory committee that meets approximately once a year, called the HTML Advisory Committee. We have presently eight members, and four of these are from U.S. companies either using or producing advanced structural ceramics, and they meet at ORNL to give us advice and guidance, and they will be meeting in ORNL on March 24th and 25th. The membership of this committee is shown in attachment 1.

I would like to close, Mr. Chairman, with a brief comment on some of our recent research results in advanced ceramics, to indicate to you that there are occasionally situations in which a research result occurs which can result in rather rapid commercialization of a product or a new material.

We some years ago recognized the brittleness problem with conventional ceramics and began some research efforts with DOE sponsorship to determine other ways, ways in which these ceramics could be toughened. I think Mr. Helms commented on this need earlier, and we have looked at three possibilities, three approaches which are delineated in the testimony. We have achieved some rather interesting properties in these materials in a short time. Now these are short-term properties, and I must stress that.

We have achieved fracture toughness values of the order of 13 Megapascal square root meters in a metastable dispersoid toughened ceramic composite with a flexure strength of 700 Megapascals. It's a very unusual set of properties for a ceramic material.

In chemically vapor deposited matrix composite work similar to the French material that Mr. Helms referred to earlier from SEP, we have demonstrated strain before failure values of the order of 1.5 percent at maximum stress values of 500 Megapascals. This is a ceramic material that can give quite a bit before it catastrophically fractures.

For whisker reinforced systems, we found that silicon carbide whiskers, when introduced in the proper way into a ceramic oxide, can cause remarkable improvements in properties. We have increased fracture toughness by a factor of three or more in aluminum oxide. That particular system has resulted in a product that has been marketed now as cutting tools. It was not the original idea for the work. These cutting tools that I have an example of here have been found to be extremely efficient in cutting cast-iron alloys and high nickel alloys, superalloys. These are being marketed by ARCO Chemical and the Greenleaf Corp.

And that's an outgrowth of some of our research in the Advanced Materials Development Program that is the responsibility of this subcommittee.

So in summary I would like to tell you that the HTML construction is proceeding well. The instrument procurement is proceeding according to plan and schedule. Plans for the organization of the new laboratory are well established. We have a concept for the user centers so that we can effectively operate and utilize interactions with both industrial and university researchers in these centers. We are very excited about this new laboratory and bringing it into operation, and look forward to seeing it contribute significantly to the solution of important national high-temperature materials problems. I would hope that at the appropriate time many members of the subcommittee can attend the dedication ceremony that we will have when we open this new laboratory.

Thank you, Mr. Chairman.

[The prepared statement of Dr. Tennery follows:]

THE HIGH TEMPERATURE MATERIALS LABORATORY
AT THE
OAK RIDGE NATIONAL LABORATORY

Victor J. Tennery

Director, HTML
Oak Ridge National Laboratory

Testimony Before the
Subcommittee on Transportation, Aviation and Materials
Committee on Science and Technology

February 27, 1986

TESTIMONY BEFORE THE
SUBCOMMITTEE ON TRANSPORTATION, AVIATION AND MATERIALS
COMMITTEE ON SCIENCE AND TECHNOLOGY

February 27, 1986

My name is Victor Tennery. I am Director of the High Temperature Materials Laboratory (HTML) at the Oak Ridge National Laboratory (ORNL) with responsibility for the construction, equipping, and operation of this new facility for high-temperature materials research. I am in the Metals and Ceramics Division at ORNL. I appear here today to discuss the High Temperature Materials Laboratory (HTML), including the status and future plans for this exciting new materials research center for the United States. In accordance with your letter of invitation, I will discuss three topics: (1) current progress of construction of the HTML, (2) plans for operation of the HTML and its facilities and, (3) proposed research thrusts in the area of high-temperature materials.

I. BRIEF HISTORY OF THE HTML

First, I will briefly review the origin of the HTML concept and how that led to the laboratory now being constructed at ORNL. In 1977, the idea which eventually became the HTML concept was formed during discussions by research staff at the Oak Ridge National Laboratory. These conclusions resulted from a series of national workshops organized by what is now the Materials Sciences Division, OBES of DOE to identify critical future materials needs for the United States. These workshops identified high-temperature materials as an area of major importance to the United States both in terms of future research and application in high technology energy conversion systems.

In 1980, an HTML Industrial User's committee was formed to assist us in identifying how the laboratory could best be organized to perform important high-temperature materials research and to assist U.S. industry in meeting foreign competition in the areas of high-temperature ceramics and metal alloys. This group included five high level industrial research managers, and was chaired by W. D. Manly, Executive Vice President, Cabot Corporation, and in this same year a conceptual design of the HTML was completed. We continued to seek input into the HTML concept from a variety of sources. In 1981, a two-day meeting was held at ORNL to review the HTML proposal with about 30 industrial research administrators to obtain their suggestions and comments on the concept. This group enthusiastically endorsed the proposed HTML.

The plan for the HTML was reviewed for the Solid State Sciences Committee, National Research Council and the Staff Director, subcommittee on Energy Development and Applications, Committee on Science and Technology. A report on the HTML was provided to the Energy Research Advisory Board of the DOE. In 1983, the request for the new laboratory was moved from the DOE OBES budget to the Transportation/Conservation budget, and the first funds for the HTML became available late in FY 1983. The FY 1986 appropriation of 2.569 M$ completed funding for this 19.169 M$ construction project. On May 17, 1985, an HTML inauguration ceremony was held at the building site, and Ms. Donna Fitzpatrick, Assistant Secretary for Conservation and Renewable Energy, and several other guests participated.

II. CURRENT PROGRESS OF CONSTRUCTION OF THE HTML

The HTML is a two-story, reinforced concrete design laboratory having a gross area of about 64,500 square feet, including 49 laboratories and 72 offices. The building was designed to be particularly stiff and be relatively vibration free in order to not impair delicate experiments and instruments. Construction of the HTML started on January 25, 1985, and should be completed by February 15, 1987. A drawing of the HTML is shown in Fig. 1; a photo of the building taken on February 13, 1986 (Fig. 2) shows the progress made toward completing the laboratory. As of February 12, the building was 50% completed and on schedule. Our experience to date indicates that the HTML will definitely be completed within the contract time, and, in fact, an early completion date is a real possibility.

III. HIGH TEMPERATURE MATERIALS THRUST AREAS FOR THE HTML

The continuing demand in the high-temperature materials area is for cost effective, more reliable materials operating at ever higher temperatures. While there is no question that high-temperature alloys will continue for the foreseeable future to be of major importance in satisfying this demand, there is a very large potential benefit in the development of ceramic materials capable of outperforming high-temperature alloys in structural applications. Presently, the U.S. ceramics industry is competing directly with Japan to develop economical advanced ceramics suitable for use in advanced diesel and gas turbine engines as well as in other applications. Because of this high level of interest and research activity in structural ceramics, we have elected to emphasize advanced structural ceramics as the major thrust area for research in the HTML. Three ORNL research groups which will be located in the new laboratory as well as the HTML User Center staff will conduct research on processing and characterization of toughened ceramics, plus chemical vapor deposition processing of ceramic matrix composites and ceramic coatings. Support for this research is anticipated primarily from DOE programs, including Advanced Materials Development Program, (Transportation/Conservation), Materials and Tribology Projects, (Energy Conversion and Utilization Technologies), Fossil Energy Materials Program, (AR&TD/Fossil Energy), and the Metallurgy and Ceramics Program, (Materials Sciences/OBES/OER).

The properties, and particularly the mechanical properties, of a ceramic body are intimately connected to the processing required to transform the starting materials into a dense ceramic material. Due to the fact that these ceramic materials are inherently brittle relative to metallic alloys, their mechanical properties are very sensitive to microstructural features on a scale of a few nanometers. The science and technology of controlling the microstructural uniformity of structural ceramics is the key objective of all the international efforts now underway in this area. The Advanced Materials Development Program in Transportation/Conservation is organized and planned to find the solution to this problem in a number of structural ceramic systems, but the FY 1987 budget value of 6.500 M$, which is a reduction of 2.146 M$ compared to the FY 1986 budget of 8.646 M$, will of course slow progress toward attainment of this important objective.

The major technical goal of the Advanced Materials Development Program in Transportation/Conservation and similar programs in DOE, in U.S. industry, and in programs in other countries is to learn how to achieve and control the required microstructural uniformity. Presently, a major scientific goal for the structural ceramic area is knowledge of the fundamental processes which determine the final microstructure of a particular structural ceramic material, and the resulting mechanical and physical properties of that material. The major technology goal in this area is the knowledge of how to identify and control all of the processing variables necessary to consistently and economically produce a structural ceramic microstructure having the required properties. Significant progress in both of these pursuits has been made in the past three years, but much greater progress is still required before structural ceramics can be manufactured with highly consistent properties at acceptable cost. A critical requirement for accomplishing this goal is the necessity to characterize rapidly a ceramic material as it progresses through the fabrication process. This is absolutely essential for properly controlling critical process variables which determine the mechanical reliability of the dense sintered ceramic.

To briefly illustrate this point, I will refer to Fig. 3, which shows the ceramic processing flow sheet of the future for the slip casting fabrication process. The process flow is shown as dotted lines. The operations identified as "characterization" within the ovals in the flow sheet signify the areas where new knowledge and new techniques must be identified and applied to manufacturing process control if we are to be able to produce high reliability ceramics. In the ceramic production process of the future, process control will be maintained based upon the results of these characterization measurements and the feedback control paths (shown as heavy lines) from these measurements to the major process operations shown as boxes in the figure.

We have selected the research instruments for the HTML with these needs in mind. These instruments, when applied to this problem and coupled to sophisticated manufacturing engineering control systems in the future, will contribute to an understanding of the type of measurements which are represented inside each of the ovals in Fig. 3. These HTML instruments are able to determine, for example, the chemistry and morphology of ceramic bodies and ceramic powders on a micro scale as well as determine their physical and mechanical properties. This strategy is already paying dividends in the initial collaborative ceramic research activities we presently have underway with industrial firms.

IV. PLANS FOR OPERATION OF THE HTML AND ITS FACILITIES

We have devoted significant time and energy to the issue of how the HTML could best be operated so as to maximize its utilization as a research center for high-temperature materials and by the industrial and university communities. We identified a growing concern in the advanced ceramic and high-temperature alloy industries about foreign competition. A particular concern focuses on how domestic companies can most effectively identify and commercialize new high-temperature materials. Many of the firms presently involved in these businesses simply do not have the resources necessary to maintain and operate sophisticated research instruments required to properly and rapidly characterize their materials on an atomic scale. It is also apparent that many university materials education departments have a growing problem in obtaining and maintaining sophisticated state-of-the-art materials characterization research instrumentation necessary for maintaining strong graduate degree programs. Strong U.S. graduate degree programs in materials are of direct importance to the long term prospects for domestic companies being able to maintain strongly competitive positions in the years to come.

The User Center Concept. Based upon these observations and conclusions, it was decided to organize User Centers in the HTML which would provide a unique, comprehensive ability to characterize advanced materials rapidly and which would be operated and maintained by a small, dedicated staff.

The HTML will include four User Centers, (1) Materials Analysis, (2) X-ray Diffraction, (3) Physical Properties, and (4) Mechanical Properties. All of the research instruments purchased in the HTML construction project will be placed in these four User Centers for use by industrial and academic researchers as well as researchers from ORNL and other federal laboratories. We are planning to provide user access to the HTML User Centers initially at no cost when the collaborative research results are public information. This policy is consistent with present operating policies of other existing ORNL User Centers.

Procurement of research instruments for the User Centers is in progress. We have developed a prioritized list of the needed equipment and plans are in place for acquiring a total of 15 major items. Procurement of the first two major instruments, a 400 KV analytical electron microscope and a high spatial resolution Auger spectrometer system is now in the bid review process. Specification preparation for eight additional instruments is well underway.

To provide convenient and efficient access to these centers, particularly by industrial and university users, we must have a dedicated staff to operate and maintain these instruments. This staff will conduct collaborative research with visiting users. We are submitting a budget request starting in FY 1987 to the Office of Basic Energy Sciences for this purpose at the recommendation of DOE. We have presented information on the HTML and, particularly, about the User Centers at numerous national technical meetings and have obtained initial statements of interest from people from more than 50 industrial firms. We have now contacted these people to obtain their suggestions on our proposed User Center operating plan. We will be receiving replies to these contacts shortly.

Initial User Center Activities. For the past three months, using HTML Pre-operational support from DOE/Conservation, we have been working on selected collaborative research problems with two industrial firms to identify effective ways to work with industrial researchers in the HTML User Centers. These organizations include Allison Gas Turbine and Cummins Engine Company.

The collaborative work with Allison Gas Turbine involves structural characterization of a domestic silicon nitride ceramic considered for use in the rotor of the AGT 100 ceramic gas turbine engine. In a period of about three months, we have determined by using high resolution transmission electron microscopy and other techniques that the static fatigue observed for this material at a temperature of 1000°C by Allison researchers resulted from microscopic void formation in the oxidic secondary phase produced in this type of ceramic material from the alumina and yttria sintering aids. Interestingly, these voids form only in the material when tensile stresses are present, and we think these observations may point the way to better understanding of the microstructural requirements for significantly improving the long term high-temperature mechanical properties of sintered silicon nitride structural ceramics.

The activity with Cummins Engine researchers is just getting underway, but it involves identifying the cause of unacceptable cracking in cordierite ceramic honeycomb, a candidate diesel particulate trap material for use on large diesel engines in the near future. We are determining if exposure of the cordierite ceramic to diesel exhaust gases results in undesirable microstructural and other property changes in this low thermal expansion ceramic material. We are using experience gained from these industrial interactions to develop the framework for the HTML Users Program to be started in FY 1987. As the HTML User Centers become fully operational, we will form an HTML User's Group, which will help us objectively identify and prioritize the research problems from outside users and from within ORNL to be addressed in the HTML User Centers.

Permanent HTML Research Staff. In addition to the four User Centers, we will also locate three of our ceramic research groups from the Metals and Ceramics Division in the HTML. Examples of the advanced ceramic materials being studied in the ORNL research groups to be located in the HTML include whisker reinforced ceramic matrix composites, chemically vapor infiltrated ceramic matrix composites, transformation toughened ceramics, and advanced suspension systems required for rapid fabrication of injection molded structural ceramic components. These research efforts are all directed at increasing the mechanical reliability of advanced structural ceramics. Co-locating them in the HTML will enhance interdisciplinary interactions, and also strengthen direct interaction with visiting users. The floor plan of the HTML, showing the presently designated locations of the four User Centers and the three ORNL ceramic research groups, is shown in Fig. 4.

HTML Advisory Committee. We have an HTML Advisory Committee of eight members, four of which are from U.S. companies using or producing advanced structural ceramics. The committee meets at ORNL to provide advice and guidance regarding HTML organization and operation. This committee is meeting at ORNL on March 24 and 25. The present membership of the committee is given in Attachment 1.

V. RECENT RESEARCH RESULTS IN ADVANCED STRUCTURAL CERAMICS

In the past couple of years, some exciting results have come from the structural ceramic research conducted in the three research groups that will be located in the HTML, and I think you will find them very interesting. As I indicated earlier, a major goal of present structural ceramic research is the correlation of microstructure with properties and the rigorous control of the microstructure during the processing required to produce a useful ceramic part or component. These two factors are crucial due to the inherent brittleness of ceramic materials. In these groups, we initiated research with DOE support some time ago to identify ways in which this detrimental brittle behavior could be mitigated by increasing the resistance of the material to catastrophic crack propagation. We are exploring the potential of ceramic matrix composites as a means for increasing the crack propagation resistance and thus increase the critical fracture toughness in this class of materials.

We are focusing on three approaches, (1) short fiber or whisker reinforcement, (2) long fiber reinforcement of chemically vapor deposited ceramic matrices, and (3) metastable dispersoid particle toughening of the matrix. We have learned via application of the skills of an interdisciplinary team of ceramists, chemists, and analytical mechanical modelers that substantial increases in critical fracture toughness can be achieved in a number of these materials without sacrificing mechanical strength. In the metastable dispersoid toughening work, we have demonstrated toughness values as high as 13 MPa $\sqrt{m}$ with strengths above 700 MPa. In the chemically vapor deposited matrix composite work, we have demonstrated strain-before-failure values up to 1.5% at maximum stress values of 500 MPa. We have recently demonstrated the ability to synthesize large tubes of this type of composite with properties similar to laboratory sized specimens. For the whisker reinforced systems, we have found that SiC whiskers in concentrations up to about 30 vol % increases the critical fracture toughness by a factor of three and the fracture strength by a factor of two and a half. This material also has outstanding thermal shock resistance, being capable of withstanding thermal shock temperature differentials up to at least 1000°C with no significant strength reduction. This type of ceramic matrix composite has recently been commercialized as a cutting tool material for cast iron and nickel base superalloys. This new advanced ceramic material is an outgrowth of our research at ORNL in the Advanced Materials Development Program (Transportation/Conservation).

VI. HTML SUMMARY

The construction of the HTML and the procurement of the research instruments for the HTML User Centers are both proceeding very well. There is a distinct possibility that the building will be completed earlier than the official planned completion date of February 15, 1987. Detailed plans are in place for the procurement of all 15 items of major research equipment.

Plans for the organization of the HTML are well established, and the concept of User Centers to encourage collaborative research between the HTML and the industrial and university research communities has been warmly received. Significant research efforts with two U.S. firms are already in progress.

We are very excited about bringing the High Temperature Materials Laboratory into operation and look forward to seeing this new national materials research center contribute to the solution of important national high-temperature materials problems, and to particularly assisting U.S. firms in their efforts to meet foreign competition in this important area.

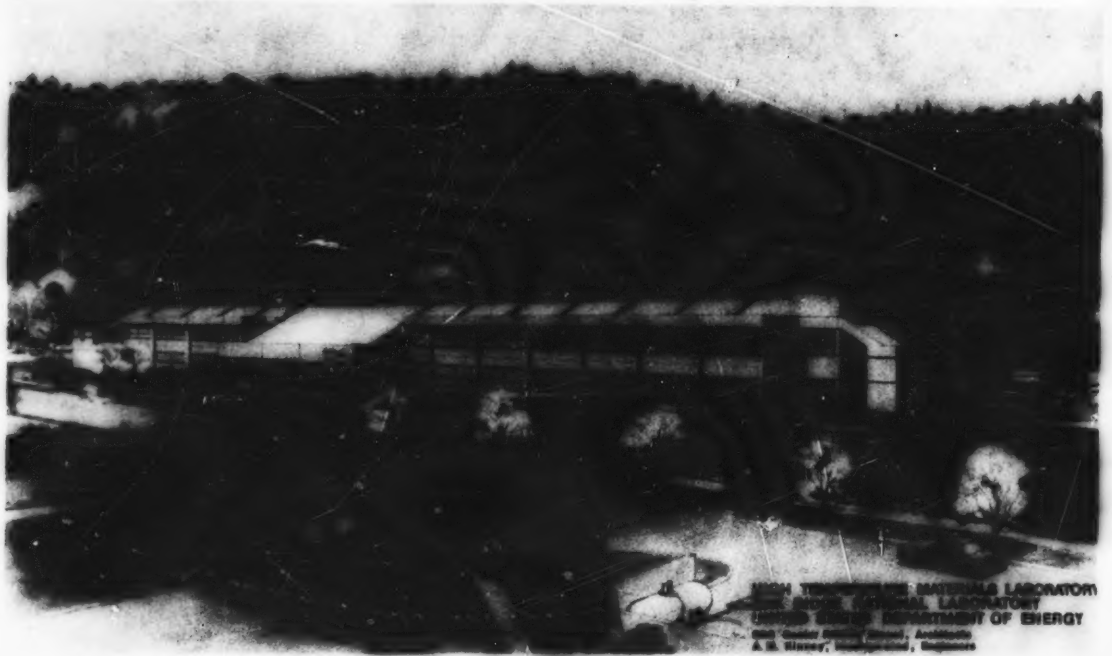

HIGH TEMPERATURE MATERIALS LABORATORY
OAK RIDGE NATIONAL LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
[illegible], Architects
A.M. Kinney, Incorporated, Engineers

FIG. 1

STRUCTURAL CERAMIC MANUFACTURING PROCESS—SLIP CASTING

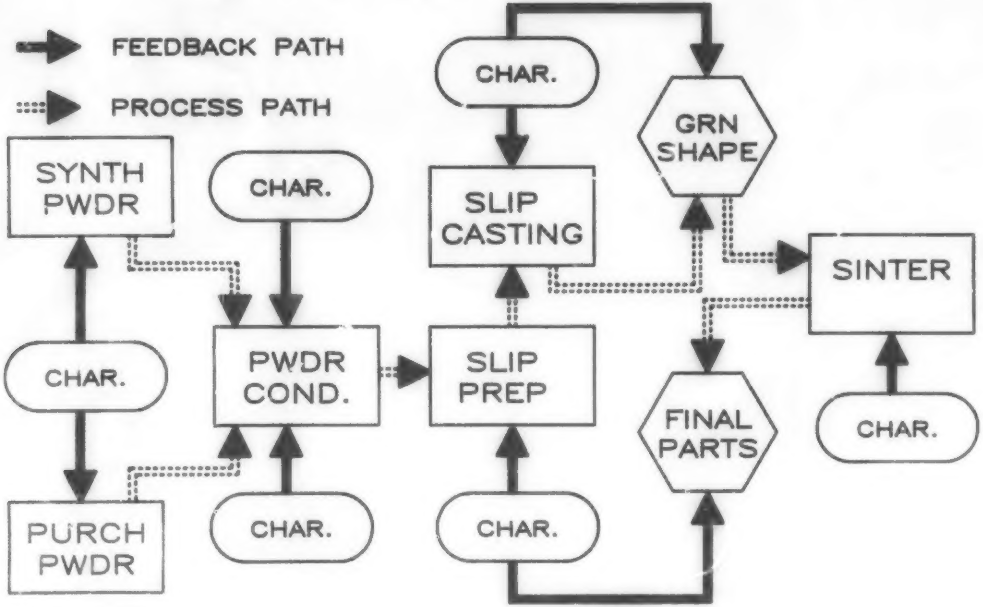

FEEDBACK PATH
PROCESS PATH
SYNTH PWDR
CHAR.
PURCH PWDR
CHAR.
PWDR COND.
CHAR.
CHAR.
SLIP CASTING
SLIP PREP
CHAR.
GRN SHAPE
FINAL PARTS
SINTER
CHAR.

FIG. 3

ORNL-DWG 85C-18237R

HTML LAB ASSIGNMENTS

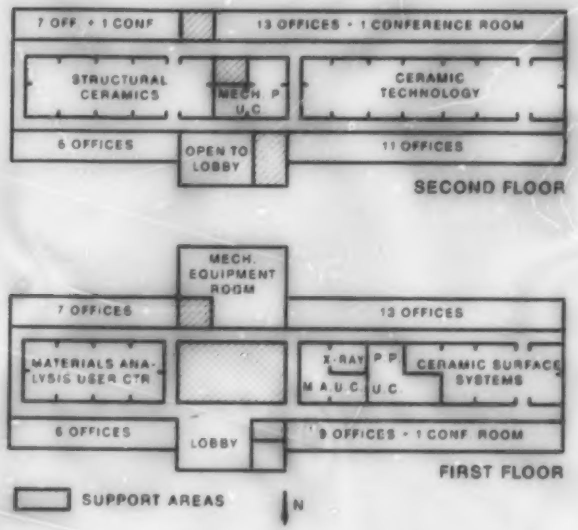

7 OFF. + 1 CONF
13 OFFICES + 1 CONFERENCE ROOM
STRUCTURAL CERAMICS
MECH. P
U.C.
CERAMIC TECHNOLOGY
6 OFFICES
OPEN TO LOBBY
11 OFFICES
SECOND FLOOR
MECH. EQUIPMENT ROOM
7 OFFICES
13 OFFICES
MATERIALS ANALYSIS USER CTR
X-RAY
P.P.
M.A.U.C.
U.C.
CERAMIC SURFACE SYSTEMS
6 OFFICES
LOBBY
9 OFFICES + 1 CONF. ROOM
FIRST FLOOR
SUPPORT AREAS
N

FIG. 4

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ATTACHMENT 1
V. J. Tennery Testimony
February 27, 1986

HIGH TEMPERATURE MATERIALS LABORATORY

Advisory Committee Members

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Department of Physics
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Mr. PACKARD. Thank you, Dr. Tennery.

I will shorten my questions because I'm due for another meeting at 12:30, but I'll be a little late for that.

Just a couple of questions to you, Dr. Halsall, first. How long do you think it will be before a marketable battery-operated automobile will be on the market?

Dr. HALSALL. Of any kind? I think that the odds of an all-purpose automobile battery is 10-plus years, because I think our changing needs on a day-to-day basis tend to make us unsatisfied with anything that won't do any purpose on any given day. I think the only direction has to be purpose-built type vehicles.

Mr. PACKARD. How far do you think the market will require, how far will an automobile have to be able to go before it will serve the needs of the public, a battery-operated automobile, before recharging?

Dr. HALSALL. If you stay with the word "automobile" then I have problems just because of the total flexibility that the average Joe using one needs. If you can allow me to slide slightly into semicommercial or purpose-directed, then of course a range of 70 miles or that order is very satisfactory and fills a high variety of needs. I am skeptical on the subject of an all-purpose automotive capacity in anything under 10-plus years, sir.

Mr. PACKARD. My questions I think was, do you think an automobile will have to go 100 miles away from its origin, 200, 300 miles before it has to come back for recharging, before it would be applicable? Do you have any figures there or, again, does it depend?

Dr. HALSALL. It's a unit sample of one. I would not be satisfied with one that did anything less than 150 miles, simply because that's the perfectly normal need that I see.

Mr. PACKARD. OK. One last question: The batteries, all the batteries that Johnson makes for a variety of companies, apparently putting their labels on them, are there any differences in them?

Dr. HALSALL. Oh, yes. Oh, yes, very very substantial. They are all based on lead-acid chemistry of one level or another. They have very considerably different energy density requirements. There is an extremely fast-moving technology relative to the new things that are needed and being called for, and I might say that some of the most demanding of the companies are the offshore ones who are driving for more and more flexibility, more and more cyclic capability, and every year you look around there are umpteen new requirements for electrical systems on cars in order to make the total energy system more economical.

Mr. PACKARD. The United States is still, I think, the front runner in battery technology. Is that true?

Dr. HALSALL. I would say we are the front runner on world technology in lead-acid chemistry. I think that we are in the process of losing our edge in sodium sulfur to Europe. I think that in the non-lead-acid areas the potential of a more sustained type of government support might undercut our capabilities. I think the problem we have is, we probably don't execute in a sustained fashion as fast as some of our world competitors, but there is no question that today I believe our technologies is still No. 1.

Mr. PACKARD. And being still No. 1, the private sector—why isn't the private sector able to pick up the research programs that the Government now is having?

Dr. HALSALL. Always, always very reasonable direction. The problem is this: The battery industry has gone through absolute turmoil in the last 10 years, where major conglomerates saw the small independent battery companies as being good targets in a super growth future, acquired them, rapidly became disenchanted with them because of the lack of profitability and the tremendous competitiveness of the industry. Over the past 5 years, four of the majors that became part of conglomerates have been spun off and either left to fend on their own or once more run back into small, highly-leveraged private concerns.

Today the industry is having a tough time as an industry. We can do work which is directed extremely selfishly toward the obvious products and goods we need in the next 1 to 3 years. We have more significant difficulties in going into the somewhat more speculative areas in directions that we believe are right, that we believe represent future needs, but because of the overall narrow margins we just plain have a tough time selling them. Frankly, in an area like zinc-bromine where we had hoped to collect some supportive funding this year, sir, while we are spending of our own corporation's money $1.5 million direct, some funding was appropriated that we had hoped to derive benefits of but it is being held up by OMB or someone similar.

There is a very real danger that in an area as speculative as this, unless some form of support can be garnered over the early future, we may simply feel that, "Hey, we would love to do it, we think it's needed, but in the competitive world of today we are just plain not sure we can support it."

Mr. PACKARD. So if we deferred the 1986 budget money, you feel that it would not only slow it down but could stop the progress of the program?

Dr. HALSALL. My understanding is that the 1986 budget money has in fact been deferred, and I see a swinging axe where we will continue on our present path probably no later than the last fiscal quarter of this year, and unless there is a reasonable change in direction, while we feel that we have a technology edge and a significant lead and would love to continue the partnership, including with the Japanese, I think the odds are very seriously that our company's management, out of respect for the needs of its stockholders, might just end up pulling the plug.

Mr. PACKARD. What do you think will be the result of closing down the Idaho National Engineering Laboratory at the end of the 1987 budget year?

Dr. HALSALL. I don't think it will have any negative impact so far as our industry's activities are concerned. If I may, I think that there is a major need for a high percentage of the DOE dollar to rightfully enter the areas where there is both a direct incentive to get something that will be producible and to get the maximum percentage of it into development activities that are of a less research nature.

Mr. PACKARD. One last question: Has the electric vehicle user tax——

Dr. **Halsall**. Task force?

Dr. **Packard** [continuing]. User task force, has that been effective, in your judgment?

Dr. **Halsall**. Yes. Yes, I think it's good.

Mr. **Packard**. Thank you.

Dr. Tennery, a couple or three questions, also, that not only I would like to ask but the staff has one.

How much is being requested for the operations of the user facility in the 1987 budget year?

Dr. **Tennery**. Excuse me just a moment. I have that with me.

Mr. **Packard**. At the same time, what will be the operational cost for 1987?

Dr. **Tennery**. The operational cost will effectively be the number that you're asking for, except for the groups that will be in the building. We are anticipating that the three groups will be funded by ongoing DOE Programs such as ECUT, the Advanced Materials Program, and basic energy sciences. The budget we are requesting in 1987 is on the order of $.68 million for the user center operation. That is $680,000.

Mr. **Packard**. You mentioned on the building construction that you're on schedule. Is it going to be on budget?

Dr. **Tennery**. Yes. Yes, indeed. This is fixed-price contract so there is no alternative that it will be on budget. After the date in February 1987, the contractor begins paying a daily penalty.

Mr. **Packard**. One last question I have for you, and I sincerely appreciate your testimony. At some point in time I want to get down to Oak Ridge.

Dr. **Tennery**. Fine.

Mr. **Packard**. That is one of the national labs that I have not been to. I would like to have the opportunity.

In high-temperature materials research, are there other materials—we have certainly dwelled a good deal on ceramics research and its applications today—is there other materials, graphite composites, any other materials that show promise?

Mr. **Tennery**. Well, there is a new family of materials, of alloys, metallic alloys that we have been for some years at ORNL—as outgrowth of the Space Power Program, in fact—done work on ordered alloys. As an outgrowth of that, some of our research had indicated that the compound Ni3AL which is the gamma prime strengthening phase in the high-nickel superalloys, could perhaps be ductilized. Earlier work on Ni3AL had indicated it was as brittle as the most brittle ceramic, very much like a glass, with a fracture toughness of probably less than 1 Megapascal square root meter. Some Japanese researchers, in fact, had indicated in one of their writings that boron, small amounts of boron, may have a very unusual effect in this compound.

Some of our researchers, particularly Chain Liu, one of the group leaders in my section at ORNL, began some research in this area and discovered that a few hundred parts per million of boron would ductilize Ni3AL and make it fabricable as any other alloy must be. Interestingly, the properties of this alloy and solid solution variants of it have indicated that it has strengths superior to Waspalloy alloys and other high temperature alloys now used in aircraft turbine engines, so there is a great deal of activity, both at our place and in industry now. I might say that a very large engine manufacturer has recently agreed to license one of the original patents issued as a result of DOE work on these alloys for the development of this alloy for large diesel engine valves.

So I would guess, in answer to your question, that ordered alloys is an area of great interest both in the Department of Defense and in other DOE program, so the action is more or less in ceramics and ordered alloys at the present time.

Mr. PACKARD. Thank you very much.

Any further questions?

[No response.]

I want to thank you, Dr. Halsall and Dr. Tennery, for your presence here and your testimony. We appreciate it very much.

I would like, just for the record, to indicate that unanimous consent will be granted for a statement of Jonathan Hinton, who was not on any of the panels, to be entered into the record. It regards the U.S. advanced ceramics work. That will be entered into the record.

Other than that, we again thank you, and we will close the hearing.

Dr. HALSALL. Thank you, Mr. Packard. I noticed that you mentioned that you had visited most of the national laboratories. I would like on behalf of industry to suggest that you come by and see how we do research, too.

Mr. PACKARD. Thank you very much.

Dr. TENNERY. Thank you, Mr. Chairman.

[Whereupon, at 12:45 p.m., the subcommittee recessed, to reconvene at the call of the Chair.]

APPENDIX

ADDITIONAL STATEMENTS SUBMITTED FOR THE RECORD

ELECTRIC
VEHICLE
DEVELOPMENT
CORPORATION

March 12, 1986

The Honorable George E. Brown
Chairman, Subcommittee on
Transportation, Aviation and Materials
Committee on Science and Technology
Suite 2321 Rayburn House Office Building
Washington, D. C. 20515

Dear Representative Brown:

In response to a request from Mr. Curt Stanford, I am providing you comments regarding the Department of Energy, DOE, FY 1986 Congressional Budget Request for Electric and Hybrid Vehicle, EHV, R & D.

The Electric Vehicle Development Corporation (EVDC) is a non-profit electric utility industry sponsored organization whose current membership represents 40% of U.S. electric generating capacity. EVDC has established a near-term objective of electric vehicle (EV) introduction into commercial fleets in the late 1980's and a longer term objective of personal vehicle introduction in the early 1990's. Our mission of EV commercialization is based on a well developed national strategic plan which emphasizes the development of the EV technology, the infrastructure and the market. Success of this mission can best be achieved through close cooperation with the Department of Energy (DOE), the Electric Power Research Institute (EPRI), the electric utility industry, and the vehicle and component manufacturers.

Throughout 1984 and 1985 EVDC has worked closely with DOE staff and the DOE Site Operators User Task force (UTF) to develop project plans and activities which are consistent with our utility industry's national strategy. This cooperative approach is vital to attaining our EV introduction objectives. The DOE FY 1987 Budget Request will have a devastating impact on the national strategy and will greatly affect our ability to successfully introduce EV technology.

Overall, a $4.44 million reduction in the 1987 budget will drastically affect the inertia established over the past several years to commercialize EVs. The DOE EHV FY 1987

G.E. Brown
March 12, 1986
Page two

Congressional Budget Request of $4.14 million will hamper the utility industry's EV introduction objective in the following ways:

- The Budget states that the "site operation testing, field evaluation, and data collection and analysis of available battery and drivetrain technology will be concluded...in FY 1987." Several electric utility companies including, Detroit Edison Company (DECO), Arizona Public Service (APS) and Philadelphia Electric Company (PE) play vital roles in the UTF. The UTF has been instrumental in providing valuable input into the development of practical EVs. UTF members such as DECO actively engage in establishing approaches necessary to introduce and support EV technology. Eliminating this vital role would jeopardize our industry's ability to commercialize EV technology.

- The Budget makes no mention of improved van development. The elimination of this project will greatly limit our chances of introducing an improved technology for test, evaluation and commercial introduction purposes. In 1985 DOE and EPRI executed a participation agreement to develop and test and improve one ton and 1/2 ton dc electric vans on a 50/50 cost shared basis. This project is reaching a successful conclusion of Phase I, Engineering Design. Additional funds are required to continue this effort to produce prototype vehicles.

- Nickel-iron battery development has been eliminated from the FY 1987 budget. The nickel-iron battery shows the most promise as the next generation for commercial fleet use. This battery is being tested at the utility industry Electric Vehicle Test Facility at Tennessee Valley Authority (TVA) and it has demonstrated performance, durability and life. However, the current nickel-iron battery design is cost prohibitive and requires additional development to reduce the materials and manufacturing cost. The premature termination of nickel-iron development will significantly limit the possibility of commercializing this battery system.

- DOE, EPRI, Argonne National Laboratory and TVA have agreed to a cost shared approach for the development of a lithium-iron sulfide battery system. This battery has significant potential for increasing the range (more than double the lead acid battery performance) and acceleration of electric vehicles. Although the utility industry is funding the largest portion of this development, continued funding from DOE would increase the potential for successfully delivering a prototype within this decade.

In summary, the drastic cut in the FY 1987 DOE EHV budget will cause a severe negative impact on the momentum established for introducing electric vehicles into the commercial sector. The U.S. utility industry has recently increased its involvement in electric vehicle development through the establishment of EVDC and the cooperative national approach to EV technology development. Each of the above project activities, the User Task Force, improved dc van development, nickel-iron battery development and lithium-iron sulfide battery development incorporate this cooperative approach through major cost share by private industry. These projects receive significant funding, at least 50%, from the utility industry except for nickel-iron battery development. Eliminating these projects in the FY 1987 will severly impact the relationship established between DOE and the utility industry and our ability to ultimately commercialize EV technology. The inability of the federal government to follow through with its commitments for R&D for EVs, at this late date, will be a tremendous waste of the tax payer dollars which have already gone into the investment of this technology.

EVDC is seeking to preserve the concept of a national effort for EV development and the cooperative approach between the utility industry and the DOE. Continued funding of the above projects will keep this "partnership" in tact. We are pleased to have the opportunity to provide input to Congressional budget hearings and we welcome any request for additional information.

Sincerely,

Gerald H. Mader
President

ghm/ck

GTE

GTE Service Corporation

4500 Fuller Drive
Irving, Texas 75062
214 659-4700

February 26, 1986

The Honorable George E. Brown,
Chairman, Subcommittee -
Transportation, Aviation and Materials
Committee on Science & Technology
Suite 2321 Rayburn House Office Building
Washington, D.C. 20515

Dear Representative Brown:

In response to a request from Mr. Curt Stanford I am providing you comments regarding the Department of Energy, DOE, FY 1986 Congressional Budget Request for Electric and Hybrid Vehicle, EHV, R&D. Specifically, I refer to the line item for the Electric Vehicle Site Operators Task Force Test and Evaluation funding. My concerns are the deferral of FY86 monies and the phase out of the Electric Vehicle R&D and Test and Evaluation in FY87. My remarks are made as Chairman of the EV Users Task Force as well as GTE's Electric Vehicle Program Manager.

The site operator User Task Force (UTF) is comprised of organizations which have been active in the DOE Electric and Hybrid Vehicle Program for the past several years. In 1982, the UTF, working in cooperation with DOE staff, established the Product Improvement Test and Evaluation Program. This program is a vital link in the technology development and technology transfer chain since it provides the proving ground for the products which eminate from the component and vehicle systems R&D. UTF not only evaluates and verifies product performance but also provides a real world environment for infrastructure development (i.e. parts supply and maintenance systems).

The UTF has been instrumental in finding and testing many components which have allowed the continued use of most of the original electric vehicles. We are now testing and aiding in the development of advanced technology components which will assist in bringing about a viable electric vehicle. The funding necessary to completing this work has been and continues to be jointly funded by DOE and the private sector. To abolish this funding when we have come so far and are so near to completion of our task seems unthinkable.

Speaking from the user's perspective, we at GTE have utilized Electric Vehicles for over four (4) years. In addition Detroit Edison Company has embarked on testing the commercially available Griffon van in cooperation with General Motors Corporation. These and other site operators programs are being carried out with corporate funding well in excess of governmental funds. All of these programs are proving very beneficial to the overall DOE program.

Through this experience we have gained an insight into the problems of the Electric Vehicle as well as an appreciation for the unique contribution the Electric Vehicle could make. It is clean, non-polluting and silent. With the proper mission assignment, it can perform well. When one considers the pollution problems facing many of our major cities, it is not hard to see a number of ways in which this clean form of transportation could aid in overcoming some of these problems.

Today we stand on the threshold of completing the development of a commercially viable electric vehicle. Most of the problems which have plagued the program have been resolved. We have good dependable short term batteries commercially available. A good midterm battery (nickle iron) could be produced without further development. A long term battery which stores sufficient energy for commercial applications, relatively inexpensive to produce and would have long life is within our grasp. This is the sodium sulphur technology. To halt the remaining R&D needed and not provide for Test and Evaluation of this technology would be to throw away all of the monies spent to date on electric vehicles.

We are concerned that by defering out this vital work a wrong signal will be sent and the electric vehicle will not come to fruition. This vehicle will be needed both from a domestic fuel standpoint and as stated earlier to provide a non-polluting urban vehicle capable of easing our air quality problems in major cities. We need your help to complete this most worthwhile program in cooperation with private industry.

Thank you for your help in this matter.

Respectfully,

C.L. Hayden
Director - Energy Management

CLH/ld

Johnson Controls, Inc
5757 N. Green Bay Avenue
Post Office Box 591
Milwaukee, WI 53201
Tel. 414 228 1200

JOHNSON
CONTROLS

Congressman George E. Brown
Chairman, Subcommittee on
Transporation, Aviation &
Materials
2324 Rayburn HOB
Washington, DC 20515

February 19, 1986

Dear Congressman Brown:

Last year at this time we expressed the critical need for funding the development of the zinc-bromine battery system for electric vehicle applications. Through the efforts of your Subcommittee and its counterpart in the Senate, funds were appropriated for a cost-sharing program for fiscal 1986.

I have recently learned that the Office of Management and Budget has deferred any spending related to this program until fiscal 1987. We are very concerned about this news and its implications on our future developmental work on the zinc-bromine system.

Without a contract in hand in the next few months, Johnson Controls funding of zinc-bromine development will be seriously jeopardized. Federal support is vital for us to win approval of spending planned for our fiscal 1987 and beyond. Indeed, we may be forced to terminate present work which we have continued at a 100% self-funded rate.

As you know, the U.S. can ill-afford to waste over 120,000 hours of privately-funded zinc-bromine research and development while Europe and Japan are accelerating their efforts. Zinc-bromine has demonstrated the potential for long life, improved performance, low cost and was, in fact, the only "advanced" battery to actually power a vehicle in this country in 1985.

Please urge the OMB to release the appropriated funding as soon as possible. We appreciate your concern for the integrity of the program. Thank you for anticipated efforts.

Sincerely,
JOHNSON CONTROLS, INC.

Vincent M. Halsall
Vice President
Battery Division

cc: Mr. Tony Taylor

SOHIO
Sohio
Engineered Materials
Company

March 24, 1986

The Honorable George E. Brown, Jr.
United States House of Representatives
2256 Rayburn House Office Building
Washington, D.C. 20515

Dear Mr. Brown:

I am writing to express the interest of Standard Oil Engineered Materials Company in DOE/NASA's FY '87 follow-on program to the Advanced Gas Turbine (AGT) project. The authorizing and appropriating subcommittees will be marking up the FY '87 request, which includes this program, in the next few weeks. We urge you to recommend continued support of this important program.

The AGT program has been very successful. The efforts of two industry teams, Garrett/Ford and Allison/Pontiac, have made great strides in demonstrating the revolutionary implications of utilizing ceramic materials in the automotive, aerospace and industrial engines of the future.

We have been a major supplier of ceramic components to both industry teams. Over the course of the six-year program, our company has received more than $10 million in ceramic development contracts and have in turn supplemented the Federal government's investments with over $30 million in capital and internal R & D expenditures to further the development and commercialization of advanced ceramics. In addition, we presently have 20 employees dedicated to AGT ceramic-related activities.

The AGT follow-on program has been designed by DOE, NASA, Industry and Academia. Its purpose is to have the U.S. become the leader in this critical technology. The means to accomplish the goal is a five-year, modestly funded effort which will refine our knowledge of state-of-the-art ceramics and, more importantly, will explore and develop the next generation of ceramic materials which hold such great promise for future commercial applications. However, we are concerned that discontinuing or substantially reducing funding for FY '87 and beyond would impair the ability of the U.S. to make use of the technology already developed, as well as jeopardize the resources committed to this program for future development.

Attached is a more detailed outline of the nature and status of the follow-on advanced gas turbine program. I hope you will find this program worthy of your support and that you will convey this support to your colleagues in Congress.

Please do not hesitate to call if you have any questions regarding the foregoing.

Sincerely,

Jonathan W. Hinton, Ph.D.
Vice President/General Manager
Structural Ceramics Division

JWH:dc
Attachment

ADVANCED TURBINE TECHNOLOGY APPLICATIONS PROJECT (ATTAP)
(Follow-on to DOE/NASA AGT Ceramic Engine Project)

BACKGROUND:

The Advanced Gas Turbine (AGT) program is scheduled to end at the close of 1986. It has been a successful, long-range effort by two industry teams - Garrett/Ford and Allison/Pontiac - to develop an advanced ceramics technology base applicable to the automotive gas turbine engine. The primary lesson learned in the AGT program was the need to further develop the materials and processes required to bring ceramics to a state of production readiness, and to maintain U.S. competitiveness with an aggressive European and Japanese government-sponsored ceramics effort. The ATTAP, designed by DOE, NASA, Industry and Academia, addresses this critical need.

BUDGET STATUS:

The FY '87 Budget request, listed in the Conservation portion of the DOE budget, under Vehicle Propulsion R&D, is $4 million.

ISSUE:

$4 Million is inadequate to perform the important work of the ATTAP. The U.S. needs to be competitive in ceramics and should encourage the continued participation of the two industry teams in the ATTAP.

ACTION:

Add $14 million to the $4 million request for ATTAP.

SUPPORTING ARGUMENTS:

Why is this program needed?

- Ceramics technology has revolutionary implications for the automotive and other transportation industries. According to a recent survey by Wards Auto World, automotive engineers cited ceramics as a material that would improve engines the most. Thirty-three percent ranked ceramics highest for 1991 while sixty-three percent did for 1996.

SUPPORTING ARGUMENTS (continued....)

_ Maintain competitiveness with aggressive R&D efforts of the Japanese and Europeans. For example, Japan's Ministry of International Trade and Industry is in the process of sponsoring a new $100 million, 8 year ceramic gas turbine program to begin in 1987.

_ To capitalize on investment already made via AGT program.
  - Paid-for test rigs
  - Paid for calibration, monitoring equipment
  - Trained staff of experts

Why a total of $18 million for FY '87?

_ Minimum required to learn what has to be learned about present and next generation ceramics technology.

_ Permit two contractor teams to continue working.
  - The U.S. needs to expand rather than narrow its base of ceramics R & D.
  - Reduce risk inherent in high technology development.

MECHANICAL TECHNOLOGY INC

March 5, 1986

Subcommittee on Transportation, Aviation and Materials
Committee on Science and Technology
House of Representatives
Washington, DC 20515

Gentlemen:

During our testimony on February 27, two questions were raised which MTI feels were answered inadequately. The questions involved the details of the payback formula in our contract and the effects of early termination on such things as payback and data rights.

From the beginning of this contract, MTI has made it clear that its role would be that of a technology developer and transfer agent. Any eventual profit to MTI would be in the form of royalties. For this reason and the fact that MTI is a relatively small company, the government felt in both the original contract negotiation and the subsequent negotiation, that a payback provision, rather than cost sharing, was the appropriate arrangement. As a result of the government's analysis, there exists in the contract, a clause requiring payment to the government of a percentage of the royalties received. The actual formula takes into account the original licensing arrangement between MTI and United Stirling of Sweden which was put into place in 1977 in order to begin transferring the technology from Sweden to the United States. Basically, the clause provides to the government between 6% and 15% of all royalties received from commercialization of the technology in vehicular applications and commercial uses other than vehicular. The payments to the government have a cap of 2.25 times the total investment in the contract, a value of over $225M at the end of 1987.

The second question involves what happens to these rights in the event of a termination. This depends largely on how the termination is accomplished. If MTI gets terminated catastrophically and improperly through an illegal impoundment (a possibility under the present "deferrals" initiative of OMB), then MTI has claim to being an "injured party" with the government clearly in breach of the contract. Under these circumstances, MTI would take the position that it owes no payback to the government. Under normal contract termination for convenience of the government, MTI would present a number of candidate items for negotiation in the termination proceedings. The payback clause would be a candidate item.

The important point, however, is that if the program is terminated prior to the end of 1987, there is really nothing yet in condition for licensing, since the MOD II will be unproven and undeveloped and the government cannot expect any payback. With the $8M requested to finish the program in 1987 (and the additional $4M in technology funds), MTI expects to fully develop the MOD II to the point where it will be a licensable entity, thereby putting the government in position to expect a payback. Royalty flows could then be expected from which the government could eventually receive as much as the $229M above mentioned.

I hope that this will clarify the situation.

Sincerely,

Lloyd R. Lawrence, Jr.
Vice President

/mf

USACA

UNITED STATES
ADVANCED CERAMICS ASSOCIATION
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Telex [illegible]

STATEMENT FOR THE RECORD OF

JONATHAN W. HINTON
VICE PRESIDENT AND GENERAL MANAGER
STRUCTURAL CERAMICS DIVISION
STANDARD OIL ENGINEERED PRODUCTS COMPANY

REPRESENTING

THE U.S. ADVANCED CERAMICS ASSOCIATION

BEFORE THE
HOUSE SCIENCE AND TECHNOLOGY COMMITTEE
SUBCOMMITTEE ON TRANSPORTATION AVIATION AND MATERIALS

FEBRUARY 27, 1986

Mr. Chairman and Members of the Subcommittee, my name is Jonathan Hinton. I am Vice President and General Manager, Structual Ceramics Division, Standard Oil Engineered Products Company. I am submitting this Statement for the Record in my capacity as Chairman of the Government Affairs Committee of the United States Advanced Ceramics Association, known as USACA. I am pleased to have an opportunity to discuss the importance of continued Federal Government funding of advanced ceramics research and development programs.

USACA

USACA is a national trade association representing over 20 companies with an interest in the emerging field of advanced ceramics. Formed on July 10, 1985, the organization is dedicated to promote free market approaches to the advancement and commercialization of advanced ceramics products and in other ways better serve the interests of the United States advanced ceramics industry. A copy of the USACA member companies is attached to my statement for information. (Attachment A).

WHAT ARE ADVANCED CERAMICS

"Ceramics" include a wide range of inorganic nonmetallic materials processed or consolidated at high temperatures. You are undoubtedly familiar with the more traditional ceramic products such as dinnerware, tile, electrical porcelain, plumbing fixtures and the like. Technological advances have provided a new, improved class of materials known as "advanced ceramics." The potential advantages of these new ceramics are widespread and are extremely important to the future material needs of the U.S.

The advantages of advanced ceramics over other materials can be summarized as follows:

- Improved hardness, wear resistance, chemical durability, optical, and high temperature capability versus metals.
- Made from elements abundant in the U.S. and therefore are not dependent upon foreign sourced raw materials.

- Once processing is adequately developed, their costs of manufacture are low as compared to other comparable materials.

- Ceramic components are generally lower in weight than metal equivalents.

- Energy saving occurs in many applications, thereby lessening dependence on imported oil.

- Ceramics offer improved durability in most applications.

- The opportunity for the U.S. to dominate a potentially very large worldwide market in the late 1990's.

Based on the oxides, nitrides and carbides of silicon, aluminum, titanium and zirconium, advanced ceramics have properties which allow them to be used in demanding environments far beyond the capabilities of metals, plastics, or conventional ceramics. The development of high-temperature ceramic materials began in the 1960s, and was largely motivated by the possibility of substantially improving gas turbines by raising their maximum operating temperatures. The material characteristics offered by the oxide ceramics of that era showed much promise. In the 1970s, several major U.S. Department of Defense research initiatives explored and advanced the experimental fabrication and utilization of ceramics in gas turbines. This work has continued into the 1980s with the U.S. Department of Energy Advanced Gas Turbine Programs. Similar efforts have been undertaken in other countries, notably in West Germany and in Japan. The U.S. Federal Government ceramic R & D work has been instrumental in contributing to the technology base for subsequent work in the U.S.

It has taken many years and considerable resources to achieve today's process capabilities and variety of ceramic material systems, involving both silicon carbide and silicon nitride, with promise of usable strength up to 1200C or higher.

ADVANCED CERAMIC APPLICATIONS

1. Today's Commercial Products

Even though the U.S. advanced structural ceramics industry is small and still highly research oriented, several commercial markets have been developed. These can be summarized as follows:

- Chemical Process Industry
  - mechanical seals
  - nozzles
  - valve components
- Oil Industry
  - flow control valves
  - blast sleeves
  - bearings
- Metals Processing
  - high temperature processing
  - burners
  - kiln applications
  - cutting tools
  - molten metal filters
- Electronics
  - semi-conductor packages
  - multi-layer capacitors
  - pressure and gas sensors
  - optical wave guides

- Automotive
    - electronic controls
    - catalytic converters
- Environmental
    - waste water treatment
- Defense
    - ceramic armor
    - submarine shaft seals
    - rocket nozzles

2. Today's Prototype Applications

Emerging/prototype applications include:

- Chemical Process Heat Exchangers
- Recuperators for High Temperature Processing Purposes
- Higher Performance Semi-conductor Packages
- Automotive Valve Train, Combustion Zone and Turbocharger Components

3. Future Applications

The real excitement and future for advanced ceramics lies in applications which need improved strength, hardness, thermal, chemical, and electrical properties, and are essential because traditional materials are unable to do the required job. For example, the high temperature resistant tiles used on the NASA space shuttles are made of advanced ceramics. We see research leading to the use of advanced ceramics in several major industries. These ceramics will be engineered to provide needed properties for the following applications:

- **Automotive**
  - new engine designs
    - ..turbine
    - ..low heat rejection (LHR) diesel
    - ..advanced rotary

- Bio-ceramics
  - artificial teeth, bones, heart valves

- Aerospace
  - high temperature low weight components for engines
  - advanced electronics
  - fuel cells

- Chemical Processes
  - advanced composites

- Electronics
  - advanced multi-layer sensing conductive packages

- Defense
  - SDI (optical/heat transfer properties).
  - improved armor for high threat levels
  - defense aerospace applications
  - advanced battle tank power trains

In the case of motor vehicles, the use of ceramic-based engines could significantly affect fuel efficiency and U.S. energy dependence. If the U.S. were to gain a technological and production advantage in ceramic-based engines, domestic automakers would have a competitive advantage in world motor vehicles markets. U.S. automobile imports would be reduced and U.S. exports would increase. Even a relatively small percentage improvement in the U.S. balance of trade in motor vehicles would have a large dollar impact on U.S. motor vehicle production and employment.

A recent study by Argonne National Laboratory cited the macroeconomic effects of U.S. or Japanese dominance in structural ceramic technology for heat engines. Under the U.S. dominance scenario, in the year 2000, U.S. real Gross National Product (1981 $) was $34.7 billion greater than the Japanese dominant scenario and employment was higher by 245,000 jobs.[1/]

FEDERAL GOVERNMENT AGENCY FUNDING OF ADVANCED CERAMICS R & D

As discussed above, advanced ceramic materials offer enormous potential to the U.S. in the automotive, bio-ceramics, aerospace, defense, electronic and chemical process industries. However, the timing and need for technological breakthrough is critical. Research on advanced ceramics has in the past been supported by several agencies of the Federal Government, including:

- Department of Energy
- Department of Commerce
- Department of Defense
  - DARPA
  - Army
  - Navy
  - Air Force
- NASA
- National Bureau of Standards
- National Academy of Sciences
- National Science Foundation

[1/] Teotia, Arvind P.S. and Johnson, Larry R., "Macroeconomic Effects of U.S. or Japanese Dominance in Structural Ceramic Technology for Heat Engines", American Ceramic Society Bulletin, (September, 1985), pp. 1232-36

R & D efforts have focused on basic research in the fundamental science of ceramics, development of dependable ceramic process technology, and development of new engineering designs to take advantage of the attributes of ceramics. It is imperative that funding at current or expanded dollar levels be maintained to ensure the continued development of new applications and advanced ceramic materials. This, in turn, will help to ensure a healthy and stable U.S. advanced ceramics industry that will be able to be competitive in a worldwide marketplace.

A March 1984 Department of Commerce report assessing the competitiveness of the U.S. advanced ceramics industry noted that there are a number of available options to strengthen the competitive position of the United States' engineered ceramics industry. Those suggested options include:[2]

"
- Increasing the amount of Federal Research and Development expenditures related to advanced engineering ceramics.
- Increasing the amount of Federal R&D aimed at military and space applications of advanced engeineering ceramics and improving the technology transfer function to commercial applications.
- Increasing Federal incentives directed toward increasing private industry R&D on advanced engineering ceramics.
- Allowing antitrust exemptions for cooperative industrial R&D to develop major advanced engineering ceramic applications and promote the Research and Development Limited Partnership (RDLP) concept for this purpose.
- Improving U.S. capacity to obtain and disseminate foreign scientific and technical information (STI).
- Increasing educational opportunities and incentives for product design and manufacturing of advanced engineering ceramics."

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[2] U.S. Department of Commerce, A Competitive Assessment of the U.S. Advanced Ceramics Industry, (March 1984), pp. xvi-xvii.

The report also suggested several options whereby the Federal Government could create or improve the market for advanced ceramics:[3]

"• Increase Federal procurement of advanced engineering ceramcis for military, space, and other applications.

- Use Federal regulatory policy to increase the market for advanced engineering ceramics.
- Provide Federal risk or liability insurance for advanced engineering ceramics producers and/or users in case of catastrophic failure.
- Review the Standard Industrial Classification codes to isolate advanced ceramics inputs and products. This would facilitate assessing developments in the industry.
- Encourage the various standards setting associations to develop, in concert with the National Bureau of Standards, preliminary reliability standards for advanced ceramics. As more knowledge is available from ongoing research programs, the standards should be revised accordingly."

The National Science Foundation identified that $44.2 billion was spent in FY 1984 for Federal Government R & D Expenditures. However, the major advanced structural ceramics R & D programs conducted by DOE, DOC, DOD, NASA, National Bureau of Standards and National Academy of Sciences account for only $50.8 million of this $44.2 billion total according to DOE documents.

Since FY 1984, total R & D funding in the Federal Government has increased to an estimated $58.3 billion in 1986[4], but the estimated funding for structural ceramics R & D has decreased from $50.8 million in FY 1984 to $45.7 million in 1986. With the Gramm-Rudman-Hollings Budget Act now before Congress, USACA is concerned about further potential cuts in the Federal Government's advanced ceramic R & D budgets for FY 87, and future years.

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[3] Ibid., p. xvii

[4] "U.S./R&D", Government Data Publications, (January, 1986), p. 8972-74.

We strongly urge Congress not to cut the essential and necessary Federal Government advanced ceramics R & D programs for the reasons delineated below.

THE NEED FOR ADDITIONAL ADVANCED CERAMICS FEDERAL GOVERNMENT R & D

1. The past and present Federal Government R & D Expenditures for Advanced Ceramics have been Successful

DOE sponsored advanced gas turbine and other Federal government advanced ceramic technology programs have made substantial gains toward their goals and have been successful in initiating an increased involvement and investment by U.S industry. Material properties of advanced ceramics have improved and net shape components with improved properties are now available to turbine engine builders. This funneling has greatly broadened the scope of design, fabrication and testing. Continuing programs at current and increased funding levels for FY 86 and 87 and beyond are needed to carry forward the accomplishments of the existing programs and to achieve the goal of developing advanced ceramic technology that will allow the industry to make future commercialization decisions. A further discussion of the Ceramic Engine Development Program is shown in Attachment B.

2. The U.S. is at the threshold of developing a healthy and stable advanced ceramic industry able to compete in worldwide markets.

The advanced ceramics industry currently encompasses two principal businesses — electronic components and structural components. The United States has lost a large part of the electronic component business to Japan due to their large investments in ceramics R & D, resulting in lower cost manufacturing technologies. At present, there is no clear indication that either Japan, Europe, or the United States has a general technological lead in advanced ceramics. However, without significant R & D efforts, the U.S. will surely fall behind. Japanese ceramic R & D appears to be aimed at process technology and materials composition improvements. This approach enables them to commercialize new products more quickly, gain production experience and reduce market prices. Therefore, continued U.S. expenditures for R & D for advanced ceramics are a critical factor in helping to ensure that the U.S. continues to be a key player in advanced ceramics technology development as this industry becomes more commercialized.

3. There still remains several key areas where Federal Government advanced ceramic R & D is needed.

We have identified three major areas where additional Federal Government advanced ceramic R & D is needed:

- Basic Research in the fundamental science of ceramics
- Development of dependable ceramic materials and processes
  - powder synthesis
  - powder processing
  - net shape fabrication and sintering
  - final machining and joining
- Development of new systems designed to take advantage of the attributes of ceramics (i.e. engines).

4. Advanced ceramics offer tremendous advantages over other materials in certain applications (as described in detail elsewhere in this testimony) and their future development is critical to the advanced material needs of the U.S.

CONCLUSION

The U.S. Advanced Ceramic Association strongly encourages Congress to continue to fund Federal Government advanced ceramics R & D at FY 86 or expanded levels. To do less, could severely jeopardize the "proof-of-concept" of advanced ceramic materials in several critical applications and, thereby, delay commercialization of vitally needed advanced ceramic materials.

We would further advocate that the Congress ensure that a mechanism exists in the Executive Branch to identify and coordinate all Federal Government advanced ceramics R & D activity to eliminate any waste or overlap. The newly created National Critical Materials Council may be the appropriate forum for this review. USACA member companies would like to extend their assistance in helping to ensure a coordinated and effective Federal Government advanced ceramics R & D program continues in the ensuing years.

ATTACHMENT A

USACA MEMBER COMPANIES

Advanced Refractory Technologies, Inc.
Aluminum Company of America
Champion Spark Plug Company
Chrysler Corporation
Adolph Coors Company
Celanese Corporation
Corning Glass Works
Dow Chemical Company
Dow Corning Corporation
E.I. du Pont de Nemours Company, Inc.
Ferro Corporation
Garrett Corporation
General Ceramics
General Motors Corporation
GTE Products Corporation
Martin Marietta Corporation
McDanel Refractory Company
Norton Company
Standard Oil Engineered Products Company
The Titan Corporation
Union Carbide Corporation
W.R. Grace & Company

ATTACHMENT B

Ceramic Engine Development

The DOE/NASA AGT (Advanced Gas Turbine) Program, initiated in 1979 has been the only true ceramic engine development program.

Funded by DOE and administered by NASA, two programs (AGT 100 and 101) have sought the goal of developing small, highly efficient turbine engines for automotive application. This goal has included functioning powertrains of about 100 hp for a 3000lb inertia weight vehicle and achieve 42.5mpg in an EPA city-highway driving cycle, or a 30% improvement over the baseline. This, of course, must be done with acceptable speed, acceleration, and driveability in a wide range of conditions.

It is anticipated that both programs will result in the operation of complete ceramic engines by the end of the program in late 1986. The engines, nearly fully developed, can then be used as test beds for additional materials/component development as well as engine design optimization.

The uniqueness of the AGT programs is that completely new engine designs have been developed. Though much development was necessary to develop the proper aero dynamics in a small scale turbine, these engines were designed for the use of ceramics from the start.

Component designs have been developed to take advantage of the favorable physical properties of ceramics while also taking into account the limits of fabrication, brittleness, strength and temperature.

New manufacturing methods, such as injection molding, have been developed as well as NDE and proof-testing techniques. A wide range of ceramic materials have been screened and characterized in actual turbine operating conditions. One of the major lessons learned from the AGT program was the need for further development of materials and processes to bring ceramics to production readiness. The purpose of the proposed Advanced Turbine Technology Application Program (ATTAP) is to accomplish this.

WRITTEN STATEMENT

BATTERY DEVELOPMENT
FOR
ELECTRIC VEHICLES

at

Eagle-Picher Industries, Inc.

Joplin, Missouri

April, 1986

Eagle-Picher Industries, Inc. is a wholly owned American corporation with corporate headquarters in Cincinnati, Ohio. The corporation is composed of twenty (20) operating divisions. It has seventy (70) plants in the United States, Canada and West Germany. With few exceptions, no two (2) plants produce the same product and each plant exists independently under its own management. Eagle-Picher is a Fortune 500 Company and currently has an annual sales in excess of $600 million.

The Electronics Division of the Corporation which is submitting this Written Statement, is chartered with the responsibility for all battery activities of the Corporation. The base for the battery activities is divided between 1) special purpose batteries and 2) commercial batteries,. The special purpose batteries support the military and weapons application as well as the space exploration programs. The commercial batteries, primarily maintenance free lead-acids and ambient temperature lithiums, serve the emergency lighting, computer standby power, electric tool and toy markets. The Electronics Division has the responsibilty for the development of batteries for the electric and electric/hybrid vehicle application.

As the impending oil crisis came into being in the early 1970's Eagle-Picher reviewed the possible candidate battery systems which could feasibly serve this application. The candidate systems which were reviewed were subsequently placed into the following categories.

Present (1975-1990)
Lead Acid (Tubular)
Lead-Acid (Advanced Flat-Plate)

Mid Term (1985-2000)
Nickel-Zinc
Nickel-Iron
Nickel-Cadmium
Zinc-Chlorine
Zinc-Bromine

Advanced
Sodium-Sulfur
Lithium/ Metal Sulfide
Iron-Air
Aluminum-Air

The overlap in time dates indicate the uncertantity at that time of the need or utilization of electric vehicles. If an oil crisis did or in the future again, come into being certainly more effort would be expended in bringing the more advanced batteries into being at an earlier time. Eagle-Picher made the decision to focus and subsequently pursue one battery system in each of the divided categories. There were as follows:

Present

Lead-Acid (Tubular)

Mid-Term

Nickel-Iron

Advanced

Lithium-Metal Sulfide

The rationale which went into that decision making process is briefly summarized below:

PRESENT: The tubular plate lead-acid was selected as it could provide slightly better energy density and slightly better (approximately 10%) cycle life than the flat plate concept. However, as it soon became apparent that the required range of the electric vehicle would be in excess of 30 miles/day, coupled at the same time with a declining market in traction batteries, the decision to terminate participation in the tubular plate battery business was made.

MID-TERM: In this category the nickel-iron battery was chosen over the other candidates due to its overall energy and power characteristics plus its lifetime capabilities. Nickel-zinc was discarded because of its poor cycle life. The zinc-chlorine and zinc-bromine systems are "flow" type systems which require auxiliary pumps to circulate the reactants and therefore seemed more appropriate for the stationary, load leveling, application rather than the mobile one. Nickel-cadmium, although possessing good cycle life, is too low in specific energy and energy density to be of use in the mobile application.

Cadmium is also a material which is in short supply and is on the "critical" resource list.

ADVANCED: The lithium-metal sulfide system was chosen over the other candidate systems because of its high energy density, good cycle life potential, no material availability problems, and system safety to the passenger and surrounding community. Sodium-sulfur appeared to have many material compatibility problems as well as a safety concern to the passenger and surrounding community . The metal-air systems have a poor energy efficiency and resolution to this deficiency seemed very difficult.

The electric vehicle offers to the United States the potential of an alternative form of transportation which would greatly reduce out dependence on imported oil supplies. This alternative mode of transportation falls into two (2) areas: 1) the commuter type vehicle and 2) the fleet type vehicle used primarily for service, maintenance, or delivery. A number of studies have been conducted which verify that over 90% of an average persons trips in a commuter type vehicle are less than 90 miles in length and fleet users have a greater than 50% of their vehicles which traverse less than 60 miles/day. In the commuter vehicle it has been estimated that a potential replacement in excess of 20 million vehicles exists while in the order of 7-8 million replacement potential exists in the fleet user area. If an oil crisis once again comes into being, an alternative fuel such as "electric" becomes increasingly important to our transportation system. The battery when fully developed can be viewed in the same light as petroleum reserves.

However, certain technical hurdles must be resolved prior to the electric vehicle becoming a viable, economically acceptable alternative. Currently the battery is the "weak-link" in the required electric vehicle system and therefore should receive a higher priority relative to work being done to resolve the shortcoming. As mentioned previously vehicle range in the order of 60-90 miles is a must. Being available at a cost which is economically viable is the bottom line. In today's economic environment, principally where gasoline seems to be in plentiful supply, there is not a large market "pull" relative to the needs of an alternative method of transportation. Subsequently there is not a large market "push" on the part of industry to bring the electric vehicle to the forefront. Because of today's lack of market demand, the responsibility of bringing the electric vehicle technology to the "viable " stage will likely fall on the government. Readiness is the key in the event of an oil availability interruption. The oil crisis of the 70's demonstrated we did not have a viable alternative transportation method. It has been our experience that a period of ten (10) years minimum is required from the time serious development is initiated until the time the product, in this case the battery, is available on a limited basis.

Eagle-Picher Industries, Electronics Division, is developing the nickel-iron battery system for use in electric and electric hybrid vehicle propulsion. Eagle-Picher has been developing the nickel-iron system for the vehicle application since late 1978. The initial development program as well as subsequent development efforts have been sponsored by the U.S. Department of Energy via the Argonne National Laboratory. The nickle-iron battery offers to the user the following advantages:

1) Increased vehicle range and vehicle utility - the nickel-iron system has the capabilty to provide the vehicle with a range of 60-100 miles depending on vehicle payload and size as well driving conditions.

2) Reduced Maintenance Costs - the single point watering system which has been developed concurrently with the base technology reduces the need for time consuming battery watering.

3) No Auxiliary Equipment Required - as the nickel-iron is a stand alone aqueous battery system no auxiliary pumps, etc. are required for its operation. A simple battery charger, either on board or in the garage, is all that is required for recharging.

4) No Equalization is Required - testing to date has shown that no unbalance of cells results after repeated discharges of the battery under the required vehicle profile.

5) Increased Reliability - with the extreme ruggedness the system offers relative to over discharge, over charging, and operating at temperature extremes, the overall reliabilty from the total battery standpoint is very good. This is not to imply the total reliability required of the vehicle is satisfied or proven today.

6) Low Life Cycle Cost - the long life of the nickel-iron system makes the cost of ownership very low in that battery replacement is not envisioned over the lifetime of the base vehicle.

The goals which have been established for the battery are listed below:

Specific Energy - 56 WH/Kg
Specific Power (peak) - 104 W/Kg
Energy Density - 120 WH/Liter
Energy Efficiency - 70% Minimum
Cycle Life - 800 Minimum
Cost - $70/KWH (1982 Dollars)

Specific energy relates to vehicle range and involves the total weight of the battery which can logically be carried in the vehicle. Acceleration of the electric vehicle must conform to minimum Department of Transportation requirements. Energy density relates to the volume the battery can occupy in the allowed vehicle space. Energy efficiency is the measure of total kilowatt-hours achieved during discharge versus total kilowatt-hours charged back into the battery. Cycle life is defined as the number of times the battery can be charged and subsequently discharged to 80% of its rated capacity. Cost is of course the bottom line in any user's mind. Cost can be viewed as an up-front one time cost as in the case of the commuter vehicle or as a life cycle cost as likely will be the case of the fleet user.

Development efforts to date have been very successful in the drive to achieve the levels of energy density, power, and cycle life necessary to make the electric vehicle a viable alternative to the IC powered vehicle. Eagle-Picher through a cooperative agreement with the Swedish National Development Company Company/SAB-NIFE has brought into the nickel-iron program advanced iron electrode technology which was not previously available in the United States. This technology is now available at our Joplin facility. The iron electrode technology coupled with Eagle-Picher's long standing nickel electrode technology has provided the base from which the present battery system evolved. To date, the base development program(s) have been funded primarily by the U.S. Department of Energy and supplemented by cost-sharing arrangements by Eagle-Picher. The development program as scoped to date has concentrated on the characterization, fabrication, and testing of the required electrodes, the fabrication and testing of full-scale cells, and finally the fabrication and testing of full-scale (270AH) six (6) volt modules. Electrodes of final configuration have now reached a lifetime of 2500 cycles . Full scale cells have presently exceeded 1200 cycles and continue to track the individual electrode tests almost identically. Most recently modules representing latest state-of-art technology have been placed under test which are demonstrating in the area of 55 Wh/Kg. The significance of this is two fold: First it demonstrates marked progress in the are of high specific energy, and secondly it demonstrates technology which lends itself to cost effective production in volume quantities. Lifetime of this technology is currently still under evaluation.

As a part of the overall Eagle-Picher Nickel-Iron Program, a number of in-vehicle engineering tests have been conducted with prototype nickel-iron batteries. The purposes of these programs are: 1) to clearly demonstrate the specific advantages the nickle-iron battery system has to offer over competing technologies and 2) to better understand and possibly reveal potential problems from a total systems standpoint as the battery is utilized in its intended environment. Tests have been completed with the Volkswagen transporter van, sedan, and pickup, and the Ford Escort and pickup. These tests have generally shown an increase in vehicle range of 2-3 times (vehicle dependent) when utilizing the nickel-iron as a direct replacement for the standard lead-acid battery pack. In addition, the Northrop Corporation is currently operating a fleet of twelve (12) vehicles utilizing the Eagle-Picher Nickel-Iron system. These tests are aimed at demonstrating the applicability of the nickel-iron system in fleet applications. Cost effectiveness with respect to battery replacement and maintenance shall also be demonstrated during the occurs of this test and evaluation program.

In summary the battery development effort has not yet realized its goals such that the vehicle range, acceleration, and weight requirements are satisfied. Specifically in the case of nickel-iron the development is deemed to be about 60% complete. It is anticipated, given FY-86 funding levels, the development should continue for an additional 3-4 years.

Presently the nickel-iron battery is viewed as the only candidate system which can offer a viable alternative to the IC powered vehicle within the next 5-10 years.

SUMMARY

VEHICLE TESTING

Eagle-Picher Industries, Inc.
Joplin, Missouri

I. VEHICLE Converted F-100 Pickup
Manufactured By Electric Vehicle
Associates
Cleveland, Ohio

II. VEHICLE Converted VW Rabbit Pickup
Manufactured By South Coast Technology
Dearborn, Michigan

III. VEHICLE VW Transporter Van
Manufactured By Volkswagen of W. Germany

		LEAD-ACID MILES	NICKEL-IRON MILES
I.	"C" CYCLE	18.7 (Varta)	62.5
	URBAN CYCLE	23.4	71.5
II.	"C" CYCLE	22.1 (Oldham)	74.8
	URBAN CYCLE	35.3	91.0
III.	"C' CYCLE	Not Tested	71.0
	URBAN CYCLE	36 (EV-106) ESB	103.0